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SONAR CONTACT CLASSIFICATION (U)

(COMPUTER SIMULATION)

by

Jack E. Helmann

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Computer Simulation

by

Jack E. Helmann
Lieutenant, United States Navy
B.S., Montana State University, 1960

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ABSTRACT

One of the most difficult problems in ASW is the classification of submarines. Presently this is done by a subjective consideration of the contact's characteristics. This simulation attempts to reproduce this subjective process. The characteristics of doppler, aspect, edge alignment, trace length and bearing width are generated and then tested. If a sufficiently high degree of characteristic consistency and correlation is present the contact is classified as possible submarine.

The study is designed to duplicate fleet sonar contact classification percentages on selected contacts for use in a computerized ASW war game.

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I. INTRODUCTION

The purpose of the simulation presented in this study is to classify surface ship sonar contacts. The approach employed is similar to the methods used by sonar operators aboard ship and thus is intended to be employed as a sub-routine in an ASW war game where the uncertainty of classification is either desired or required.

The simulation is designed to duplicate present fleet percentages of correct classification on a few selected submarine and non-submarine targets. No attempt has been made to improve present classification results for the following reasons:

1. Data concerning the accuracy of a sonar operator correctly detecting contact characteristics, such as doppler, for each transmission of a series of transmissions is not available. Thus the probability curves used to obtain each contact characteristic are subjective opinions of the author.

A sensitivity analysis was run on these curves and is described in a later section.

2. The list of characteristics does not include use of the modern equipment such as ASPECT that is presently installed on some of our surface ships. Only characteristics obtainable on any ASW ship were used.

3. The scope of the study was limited by the amount of time available for research and therefore prevented the inclusion of more contact types and contact characteristics. Thus any attempt to improve

existing classification would be hurriedly made and probably inaccurate. (Stanford Research Institute has an in-house study similar to this thesis under-way. Their purpose is to develop a program for fleet use.)

As far as can be determined, the method employed in this computer simulation is unique. It is hoped that eventually some of the ideas of this program can be incorporated into a useful and accurate classification system for fleet use, possible in connection with NTDS.

The computer program itself is written in FORTRAN 63 and is unclassified.

Section II of this paper provides a detailed description of the model and Section III contains a discussion of the results. There are appendices for the probability curves and comparison matrices used and a general logic flow chart of the program.

II. MODEL DESCRIPTION

A. Basic Assumptions

> "There is no single attribute of a submarine target capable of being sensed by a sonar that clearly distinguishes it from the wide variety of non-submarine targets that also can be sensed by a sonar. Consequently, it is absolutely mandatory that as many as possible of the target's major attributes be determined during the classification process and that the indicated attributes be combined in a logical fashion to determine the probable nature of the target."[7]

The theme of this quotation and of the many publications dealing with sonar contact classification is that classification is a difficult but logical process of information collection and evaluation. The computer simulation presented in this study is an attempt to systematize the evaluation and collection of contact information by a set of logical rules.

Five basic assumptions were necessary before the idea for the simulation could proceed into the development stage. First, only five contact characteristics are used. These are doppler, aspect, edge alignment, trace length and bearing width. The original ideas and values for these characteristics come from Tables 2-1 and 3-1 of NWIP 24-1(A), ANTISUBMARINE CLASSIFICATION MANUAL, and from the decision matrix of the Hand Held Information Processor (HHIP).

The second assumption concerns which contacts out of the multitude available to attempt to classify. The following seven were chosen: submarines (nuclear and conventional), whales, fish, pinnacles, bottom,

ridges or reefs and moving submarine decoys. These contacts represent several of the general areas which produce contacts and seem the simplest to quantify.

The third assumption deals with the selection of information sources available to the detecting ship. "The conventional sources of this information are the PPI, Audio and TRR displays presently associated with active sonars."[12] Since these three sources are the only classification devices available to all ASW surface ships, the characteristics of the contacts developed in this study are those obtained from the Tactical Range Recorder (TRR) and the AN/SQS-23 sonar. Sonars with different transmitting frequencies could be used, if the data for doppler determination were revised to confirm. A part of this assumption is that the operators use the equipment in the manner designed for best data collection.

Assumption four is that only one contact will be classified at a time. Once a detection has been made, classification of that contact must be completed before a new contact can be considered.

The last assumption basic to the simulation is that the contact must be classified at the end of five sonar transmissions (pings).

> "It is important to remember that the classification decision may have to be made at an arbitrary point in time for tactical reasons....Obviously the tactical situation may demand that certain action be taken before a particularly critical target range is reached. If so, classification is simply as good as the information accumulated until that time....The classifier cannot anticipate how early the crucial clues will

show themselves or even if certain ones will appear. His responsibility, therefore, is to classify continuously with whatever level of certainty all the accumulated evidence permits. Whatever the tactical situation, he will then have the best obtainable solution at all times."[17]

The limit of five transmissions would fall into the wartime tactical situation. For the SQS-23 sonar it would generally take about one minute to obtain and evaluate the evidence from five pings. For present day, high speed task forces and nuclear submarines even one minute may be too long.

The output of the simulation, a classification of either SUB or NON-SUB, is based on computed contact characteristics. The consistency and correlation of these characteristics gives a value to a weighting equation, with the magnitude of this value determining the final classification.

B. Classification System Outline

A description of the logic of the simulation is contained in this section. The details of the individual contact characteristics are discussed in the next section and a flow chart of the program is contained in Appendix II.

After a target has been detected, it is transferred to the classification subroutine. This subroutine is in no way involved with the detection itself. In fact, once a detection has been made, the contact

is assumed to be detected on the next N-1 consecutive transmissions of the sonar. N is an input parameter to the program ($1 \leq N \leq 99$) and is set at 5.

The main program is then interrogated as to the type of contact detected; its course, speed, range and bearing; and the course and speed of the detecting ship. With the above information, target angle (aspect) and target speed in the line of bearing are computed. The characteristics of the target are then generated, each in separate subroutines of the simulation program. Determination that a contact is either a surface ship or a surfaced submarine is accomplished by testing the contact designation. An immediate exit is made to the detecting program prior to any characteristic generation, and the contact is identified as either surface ship or surfaced submarine.

The logic employed in each characteristic subroutine is very much the same and will be explained in detail in the next section. The following example will briefly illustrate the procedure. Numerical values for the example are obtained from appropriate curves in Appendix I.

Suppose the contact is a whale with an aspect angle of 121 degrees and a speed in the line of bearing of 2.2 knots. To generate a value of trace length, the simulation program generates a normal distribution that has a probability of .91 of indicating that the contact's trace length is less than 30 yards. A submarine with the same aspect and speed

would have a probability of .74 of having a trace length between 30 and 70 yards.

At this point in the classification procedure the contact has a value for each of the five characteristics. Contacts used in the design and testing of the program were derived from maneuvering board solutions.

Correlation and consistency checks of the generated characteristics must now be made.

> "The aspect of the target is regarded as a 'unifying concept' in target classification for a very simple but important reason. Because the size and shape of submaring targets are generally specifiable in advance, we can demand that the sonar display the target characteristics in certain logical patterns. And since the sonar 'senses' different things about submarines at various aspects, the indicated aspect becomes the basis for deciding whether a given pattern of information logically could have been produced by a submarine target."[17] "When they're incompatible with the remainder of the cue set, pip shape and doppler are given the greatest importance in reaching the classification decision."[1]

Using the idea that doppler and aspect are the two most important characteristics, their derived value is compared with the values of all other characteristics on each ping. This comparison gives nine separate comparison matrices. Each contact is evaluated by the matrices and given points depending upon the degree of correlation between the two characteristics being checked. These points are added and the sum is averaged for the N pings and the average becomes a sixth classification characteristic in the final weighting equation.

For example, if the derived value of doppler is up (not necessarily the true value) and the derived trace length value is less that 30 yards, no points are given to this contact by the doppler vs. trace length matrix. Up doppler indicates some type of bow aspect but a trace length of less than 30 yards would indicate a beam aspect target, thus resulting in zero correlation. The points in all nine of these matrices are based on the correlation a submarine target would have. Regardless of what the contact really is, the question being asked, and eventually answered, by this program is the following: Is the target sufficiently like a submarine to be classified as a submarine?

After the correlation of characteristics for each ping has been checked, the consistency of each characteristic over the N pings is checked.

This consistency check is accomplished in the following manner. From the second ping through the Nth ping the present value of each characteristic is checked against the immediately preceding value of that characteristic to see if the values are the same or if they have changed by an amount less than or equal to the change a submarine could have effected by evasive maneuvering.

Consider a short example using the characteristic of aspect. Suppose on the third ping the contact indicated a computed aspect of port bow, and on the fourth ping an aspect of starboard quarter was noted. The time interval between pings should be no more that ten seconds (target range of approximately 8000 yards) and the most

maneuverable submarine, even at high speeds, can only turn about forty-five degrees in ten seconds. Thus, the contact's change in aspect, which indicates a turn of about one hundred degrees or more, is not consistent with a submaring target and would receive no-consistency points for aspect at ping four. If the aspect had only changed to port beam then points would be given because the change is feasible for a submarine.

Additional points are given if the doppler indicates a target speed of greater than eight knots, or the edge alignment shows wake, since these are excellent submarine indicators. No points are given, regardless of consistency, if trace length is greater than 130 yards or bearing width is greater than 30 degrees, because these indications are inconsistent with submarine values.

These points are summed for each characteristic over N-1 pings and give the other five terms used by the weight equation.

At this point the final classification decision must be made. To make this decision the following equation,

$$WT = A(\mathrm{DOPPLER})^u + B(\mathrm{ASPECT})^v + C(\mathrm{EDGE})^w + D(\mathrm{TRACE})^x + E(\mathrm{BEARING})^y + F(\mathrm{CORRELATION})^z$$

is evaluated. If this equation yields a point value greater than a set value then the contact is classified a possible submarine. The cutoff value and the coefficients and exponents of this equation are discussed in Section III.

The entire idea of correlation and consistency of target return as combined into this weighting equation is explained by the following quote,

> "Non-submarine targets of many types can produce a multitude of submaring-like indications in the displays. At one time or another they can produce doppler, strong echoes, sharp echoes, echoes having submarine shapes and sizes, echoes of appropriate length, alignment and structure. But they rarely produce a lasting pattern of information that describes a submarine at a single aspect (or gradually changing aspect)."[17]

The cutoff value of the classification equation is chosen to give a correct classification of approximately 75 percent. This percentage is chosen because it is approximately the value obtained by sonarmen on actual contacts.[5]

Table 1 gives a breakdown of percentage of correct classification for each contact type and percent of occurrence of each contact.

TABLE 1

Contact Occurrence and Classification Percentages

Contact	% of Occurrence (5)	% of Correct Classification [10]
SUB	47	80
FISH	18 [3]	70
WHALE	10	60
BOTTOM	9	99+
RIDGE/REEF	7	99
PINNACLE	5	70
DECOY	4	15

Since many other contact types make up the entire set of all sonar contacts, the percentages above reflect the ratio of each contact type used to the total number represented by these seven contacts. Both percentages given for moving submarine decoys are estimates made by the author.

At this point control returns to the parent program with the final classification of sub or non-sub.

C. Contact Characteristics

The choice of doppler, aspect, edge alignment and trace length as four of the five contact classification characteristics is relatively simple. Doppler and aspect, as pointed out in the previous section, are considered by sonar operators as the two most important characteristics a contact can display. The inclusion of edge alignment and trace length follows the trend of current mechanical and electrical classification aides to use the trace information of the TRR. This trace has proved valuable, one of the main reasons being that a continuous and permanent record of the contact is maintained. Thus the use of these four characteristics is justified on the basis that they are currently being heavily used for contact classification.

Bearing width is chosen as the fifth characteristic for less significant reasons. First, since it is a quantitative characteristic, it can readily be included in a computer simulation. Another characteristic such as echo strength or echo quality requires numeric

interpretation of terms like mushy, strong, metallic. Secondly, it is significant in the elimination of large targets such as bottom or ridges. It was felt that in order to obtain a classification after a limited number of transmissions at least five characteristics were required. Of all the contact characteristics that NWIP 24-1(A) lists as major classification aides, bearing width gives the greatest contribution to final classification and so is included in the simulation.

Subordinate groups of contacts tend to appear for each characteristic. Moving contacts have similar doppler presentations, while whales and decoys have the same edge alignment, trace length and bearing width characteristics. Table 2 summarizes the contacts that form sub-groups for each characteristic.

Since the value of each characteristic is computed in a separate subroutine of the simulation each will be discussed separately. The first characteristic -doppler- will be used to explain the derivation of the probability curves used to generate the characteristics. Probability curves for each characteristic are shown in Appendix I.

Contact Groupings for Characteristics

Table 2

Characteristic	1	2	3	4	5
Doppler	Submarine Whale Fish Decoy	Bottom Ridge Pinnacle			
Aspect	Submarine Whale Pinnacle	Decoy	Fish	Bottom Ridge	
Edge Alignment	Submarine	Fish Bottom	Whale Decoy	Pinnacle Ridge	
Trace Length	Submarine	Whale Decoy	Pinnacle	Ridge	Fish Bottom
Bearing Width	Submarine	Bottom Ridge Fish	Whale Decoy	Pinnacle	

Doppler. Doppler is the frequency change between the reverberations and the portion of the sound return produced by a target. This change is caused by the component of motion of the target in the line of bearing and/or motion of water across the target, such as current.

Three basic values of doppler are generated in this simulation. Up doppler implies a contact speed in the LOB (line of bearing) of greater than 1-1/2 knots (closing), down doppler for contact speeds less than -1-1/2 knots (opening) and no doppler for contacts with speeds greater than or equal to -1-1/2 knots and less than or equal to 1-1/2 knots.

The amount of doppler present on any ping is dependent upon the transmission frequency of the sonar and the component of target motion in the LOB, as shown in formula 1.[6]

$$\Delta f = .69f \ \Delta v$$

(1) Where Δf = doppler shift in cps
f = donar frequency in kcps
Δv = target motion in LOB (kts)

The SQS-23 sonar has a transmission frequency of five kilocycles, and consequently gives a poor doppler presentation for low contact speeds. The audio return is heterodyned to a frequency of 800 cps. While at this frequency the human ear requires a low signal-to-noise ratio for detection purposes the ratio $\Delta f/f$ for frequency shift determination requires a frequency difference of 4.6 cycles.[8] From formula (1) a speed of 1-1/2 knots gives $\Delta f = 5.3$ cps, which is

just above the detectable threshold. Thus the use of an interval for no doppler was prompted, not by the absence of doppler at low speeds, but by the inability of the human ear to distinguish doppler.

It is realized that only operators with acute hearing will detect this threshold value, and thus the probability of distinguishing up doppler about the point 1-1/2 knots is approximately equal to one-half. Even with the AN/SQS-10 sonar the probability of detecting motion of a target with a speed of 1-1/2 knots was about three-quarters, although at speeds greater than 3 knots correct doppler detection was almost certain.[4]

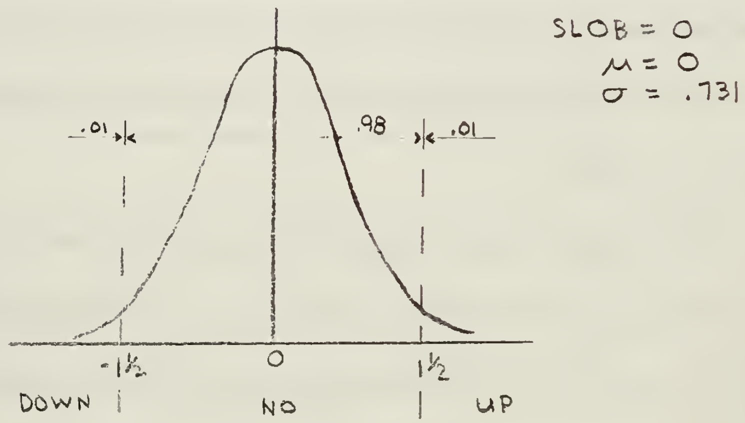
The curves for the doppler reported by the sonar operator are normally distributed with mean, μ , and standard deviation, σ . They represent the probability that the operator will indicate the true value of the doppler, either up, down or no. In other words the curves give the probability that, if the doppler is up, the operator will say it is up. All normal curves are generated using twenty uniformly distributed random numbers and the central limit theorem. A normal distribution was chosen for the characteristic curves because of the symmetry of the curve which allows equal error on either side of the mean and the fact that the curves are not truncated but allow probabilities under both tails.

The set of sonar contacts are divided into two sub-sets for doppler generation.

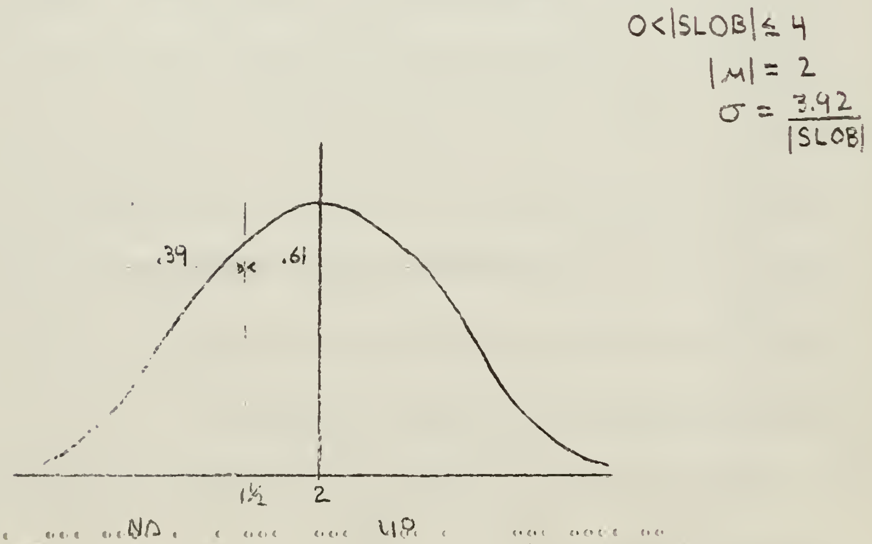
1. Submarine, decoy, whale, fish

These contacts have four separate normal curves for their doppler presentation that are based on the actual speed in the LOB of the contact. (The same curves are used for plus or minus speed.) The following curves have been used for the indicated values of speed in the LOB(SLOB).

a)

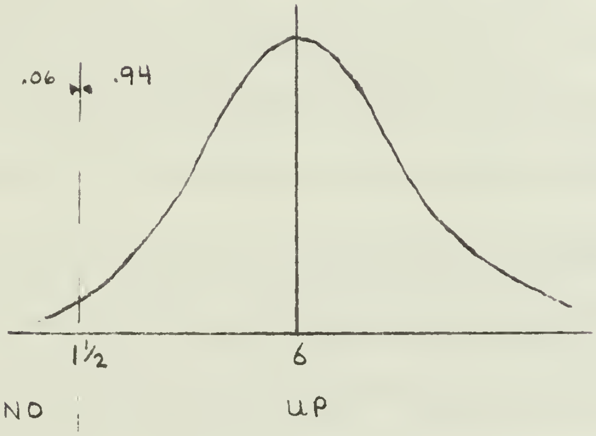


b)



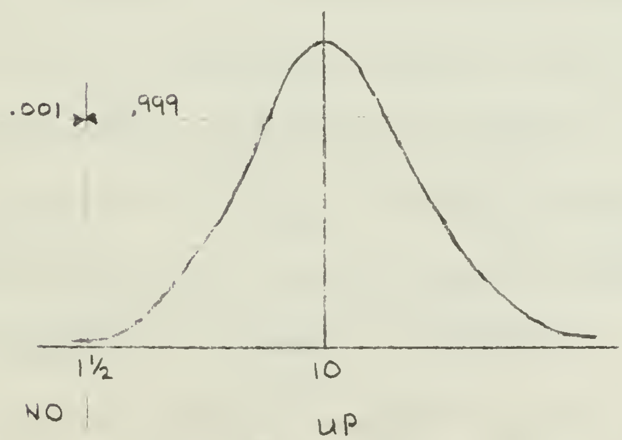
c)

$4 < |SLOB| \leq 8$
$|\mu| = 6$
$\sigma = \frac{18}{|SLOB|}$



d)

$8 < |SLOB|$
$|\mu| = 10$
$\sigma = \frac{275}{(SLOB)^2}$



The mean in each case, except for the case when $|SLOB| >$ 8 kts, is the midpoint of the interval. The standard deviation is chosen so that as the absolute value of true speed becomes less than the mean the standard deviation becomes larger and thus the curve becomes flatter. Also when the absolute value of true speed becomes greater than the mean, the standard deviation decreases and the curve becomes higher and narrower. For example, if a contact's speed is 3.8 kts, the standard deviation of the curve becomes less and the probability of up doppler increases, as would be expected. Because of the lack of data the mean and area under the curve were chosen by the author, and the standard deviation was then designed to meet the above requirements.

2. <u>Pinnacle, bottom, ridge</u>

These contacts always have a true speed of zero, but in some cases the presence of currents or tides will cause a compression of the sound beam and give an indication of doppler. Therefore, it is necessary to allow a small probability, say .005 in either direction, of up or down doppler. The form of the curve is similar to the curve for subset one where SLOB = 0, except $\sigma = .645$; $\mu = 0$.

An example of doppler generation will now be discussed. Given a submarine decoy with a true speed in the LOB equal to 1.7 kts. The computer will then generate twenty uniform random numbers and convert them to a standard normally distributed number in the following manner:

$$x = N(0,1) = \frac{\frac{1}{20}\sum_{i=1}^{20} R_i - .5}{\sqrt{1/240}} \qquad (14)$$

To convert this number to fit doppler curve set 1-b, the following transformation is used:

$$y = \sigma x + \mu$$

and this value is tested for up, no or down doppler.

The method of characteristic generation outlined above is employed for all normal probability curves in the simulation.

Aspect. Aspect angle of the contact is one of the most important inputs to the simulation. It is used in the determination of every characteristic in one form or another. However, the true target angle, or aspect angle, is in itself an important classification aid. It is defined as the relative bearing of the contacting ship from the contact.

Figure 1 shows the limits of each aspect, in degrees relative, and its name.

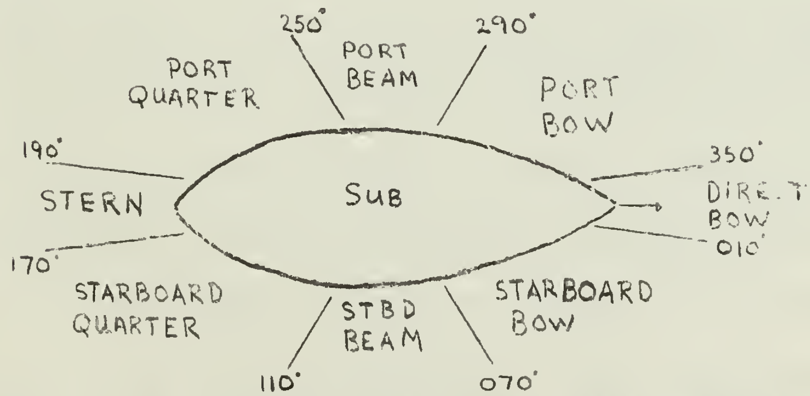


Figure 1
Submarine Aspects

Contacts are subdivided as follows:

1. Submarine, whale, pinnacle

For these three contacts the eight basic aspects shown in Figure 1 are separated into twenty intervals. This breakdown is shown in Table 3. The true aspect angle is α , μ is the mean of the interval and σ its standard deviation. These twenty intervals were developed to insure that adequate coverage is given all aspects and to allow the standard deviations of each interval to vary with the true value of aspect. The form $\sigma = k + 1/k\,(\alpha - \mu)$ was devised so that as the true aspect angle approaches the border of the interval in which it is contained, the curve flattens so that a higher probability of being incorrect results. ($K = \sigma$ when $\alpha = \mu$.) For example, an aspect angle of $\alpha \doteq 249$ degrees should have approximately equal probabilities of being either port quarter or port beam while a value of $\alpha = 318$ degrees should always be port bow.

2. Decoy

Due to its small size and lack of wake, this type contact always appears to be a beam aspect submarine. Thus for true aspect angles from 0° to 180° it appears as a starboard beam submarine and from 180° to 360° a port beam submarine appears. For the former interval, $\mu = 90^{\circ}$ and for the later, $\mu = 270^{\circ}$. In both cases $\sigma = 29 + .1|\alpha - \mu|$ which again gives the flattening effect to the curve as α approaches the end points of the interval.

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TABLE 3

SUBMARINE ASPECT INTERVALS

ASPECT	INTERVAL	MEAN	STANDARD DEVIATION
BOW	$0° \le \alpha \le 10°$	$\mu = 5°$	$\sigma = 7.3 + \frac{1}{7.3}(\alpha - 5°)$
STBD	$10° < \alpha < 30°$	$\mu = 20°$	$\sigma = 9.64 - \frac{1}{9.64}(\alpha - 20°)$
BOW	$30° \le \alpha \le 50°$	$\mu = 40°$	$\sigma = 10.72$
	$50° < \alpha < 70°$	$\mu = 60°$	$\sigma = 9.64 + \frac{1}{9.64}(\alpha - 60°)$
STBD	$70° \le \alpha < 90°$	$\mu = 80°$	$\sigma = 5.32 - \frac{1}{5.32}(\alpha - 80°)$
BEAM	$90° \le \alpha \le 110°$	$\mu = 100°$	$\sigma = 5.32 + \frac{1}{5.32}(\alpha - 100°)$
STBD	$110° < \alpha < 130°$	$\mu = 120°$	$\sigma = 9.64 - \frac{1}{9.64}(\alpha - 120°)$
QTR	$130° \le \alpha \le 150°$	$\mu = 140°$	$\sigma = 10.72$
	$150° < \alpha < 170°$	$\mu = 160°$	$\sigma = 9.64 + \frac{1}{9.64}(\alpha - 160°)$
STERN	$170° \le \alpha < 180°$	$\mu = 175°$	$\sigma = 7.3 - \frac{1}{7.3}(\alpha - 175°)$
	$180° \le \alpha \le 190°$	$\mu = 185°$	$\sigma = 7.3 + \frac{1}{7.3}(\alpha - 185°)$
PORT	$190° < \alpha < 210°$	$\mu = 200°$	$\sigma = 9.64 - \frac{1}{9.64}(\alpha - 200°)$
QTR	$210° \le \alpha \le 230°$	$\mu = 220°$	$\sigma = 10.72$
	$230° < \alpha < 250°$	$\mu = 240°$	$\sigma = 9.64 + \frac{1}{9.64}(\alpha - 240°)$
PORT	$250° \le \alpha \le 270°$	$\mu = 260°$	$\sigma = 5.32 - \frac{1}{5.32}(\alpha - 260°)$
BEAM	$270° < \alpha \le 290°$	$\mu = 280°$	$\sigma = 5.32 + \frac{1}{5.32}(\alpha - 280°)$
PORT	$290° < \alpha < 310°$	$\mu = 300°$	$\sigma = 9.64 - \frac{1}{9.64}(\alpha - 300°)$
BOW	$310° \le \alpha \le 330°$	$\mu = 320°$	$\sigma = 10.72$
	$330° \le \alpha \le 350°$	$\mu = 340°$	$\sigma = 9.64 + \frac{1}{9.64}(\alpha - 340°)$
BOW	$350° \le \alpha < 0°$	$\mu = 355°$	$\sigma = 7.3 - \frac{1}{7.3}(\alpha - 355°)$

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3. Fish

While decoys always give a beam aspect presentation on the PPI, fish never give the appearance of a beam.[18] Their presentation is either bow, stern, or quarter. For an aspect angle between 090° and 270°, fish aspect changes from starboard quarter to stern to port quarter and as the aspect angle goes from 270° to 090° the aspect presentation varies from port bow to direct bow to starboard bow.

For the interval $090^{\circ} < \alpha < 270^{\circ}$, $\mu = 180^{\circ}$ and for $270^{\circ} \leq \alpha \leq 090^{\circ}$, $\mu = 0^{\circ}$. In both cases $\sigma = 27^{\circ}$. This constant standard deviation causes the appearance of either direct bow or stern aspect more frequently than any other aspect and this is in keeping with actual operating occurrences.

4. Bottom, ridge

The aspect angle for these two contact types is a uniform distribution with all aspects equally likely. This distribution results because of a lack of any definite aspect trend among these types of contacts. The irregular surfaces of these contacts reflect the sound beams back in different patterns on successive pings even if the contacting ship has moved very little. Thus the appearance of the contact on the PPI scope can and does change radically from ping to ping. Therefore each aspect type is made equally likely by the uniform distribution.

Edge Alignment. The overall alignment of both left or leading edge and right or trailing edge of the Tactical Range Recorder (TRR) traces, especially when coupled with aspect and doppler presentations, gives a good indication of contact classification. The indication of wake in these traces is especially important for separating submarine and non-submarine targets.

Edge alignment presentation is divided into categories of good, fair, poor and wake. The category of highlights was considered but later rejected because it rarely appears with the long wave length, low frequency transmission of the SQS-23 sonar. The description of the edge alignment presentation and the relation of each type of alignment to submarine/non-submarine targets was taken from the HHIP decision matrix and NWIP 24-1(A).

For generation of edge alignment the various contacts are divided into four groups. Note that this is the first characteristic discussed for which submarines have a different group of probability curves than any other contact.

1. Submarine

Generally left edge alignment is good for bow and beam aspect targets, fair for quarter aspects, and poor or wake for stern aspects. The converse holds for right edge alignment.

There are three basic groups for the alignment generation of each edge.

Table 4

Submarine Edge Alignment Intervals

Edge		Interval	Mean	Standard Deviation
LEFT	1	$0^\circ \le \alpha < 70^\circ$ $290^\circ < \alpha < 360^\circ$	$\mu = 0$	$\sigma = .859$
	2	$70^\circ \le \alpha \le 110^\circ$ $250^\circ \le \alpha \le 290^\circ$	$\mu = 0$	$\sigma = 1.14 + .06(\alpha - 90^\circ)$ $\sigma = 1.14 + .06(270^\circ - \alpha)$
	3	$110^\circ < \alpha < 180^\circ$ $180^\circ \le \alpha < 250^\circ$	$\mu = 0$	$\sigma = 1.39 + .05(170^\circ - \alpha)$ $\sigma = 1.39 + .05(\alpha - 190^\circ)$
RIGHT	1	$0^\circ \le \alpha < 70^\circ$ $290^\circ < \alpha < 360^\circ$	$\mu = 0$	$\sigma = 1.39 + .05(10^\circ - \alpha)$ $\sigma = 1.39 + .05(\alpha - 350^\circ)$
	2	$70^\circ \le \alpha \le 110^\circ$ $250^\circ \le \alpha \le 290^\circ$	$\mu = 0$	$\sigma = 1.14 + .06(90^\circ - \alpha)$ $\sigma = 1.14 + .06(\alpha - 270^\circ)$
	3	$110^\circ < \alpha < 250^\circ$	$\mu = 0$	$\sigma = .975$

In Table 4, α is the true aspect angle, μ is the mean of the probability distribution, not the aspect interval, (see curves in Appendix I) and σ is the standard deviation of the probability distribution.

Submarine edge alignment is dependent upon speed as well as aspect angle. A submarine sitting dead in the water will not give an indication of wake, in fact both edges should have good or fair alignment from all aspects. However, a moving submarine generally has one edge with good alignment and the other with a poor or wake presentation except at beam aspects. This factor does not apply to any of the other contact types.

2. <u>Fish, bottom</u>

Both left and right edge alignment of these contacts is either fair or poor and definitely tending toward the latter. A school of fish will

move around rapidly and many times give multiple echoes. Also, sound may ripple off the bottom or present multiple echoes from small peaks or have many other varied and unpredictable returns.

3. Whale, decoy

Whales and moving decoys have similar edge alignments. Unlike fish and bottom their alignment is very much like a beam aspect submarine, usually well aligned with a smooth geometrical curve for both edges. Thus in the case of whales and decoys the same curve is used to generate alignment for both edges.

4. Pinnacle, ridge

The nature and shape of these contacts gives different returns for the separate edges. The leading edge tends to be sharper, better defined, and better aligned; while the trailing edge tends to trail off and have poorer alignment. Because of this separate curves are required for each edge.

Trace length. Trace length is the length in yards of the echo trace. It reflects the approximate extent of the target in the direction of the sound beam. This information is useful since the physical dimensions of submarine targets are known within relatively narrow limits. Thus the extent of the echo trace that can be considered acceptable from a presumed submarine target at a particular aspect can be specified.

"All echoes produce traces of some definable length. For the submarine target this length commonly varies from approximately 20 to 120 yards depending upon the aspect of the target."[17] This simulation makes use of this idea by dividing the characteristic of trace length into four intervals:

a. $L \leq 30$
b. $30 < L \leq 70$
c. $70 < L \leq 130$
d. $130 < L$

L = trace length in yards

These intervals are the same as used by the HHIP classification device.

Again, as in the previous section, submarines have a set of probability curves different from all other contacts. The curves for submarines are also dependent upon contact speed. A moving submarine can give a wake presentation which will appear on the TRR and increase the trace length of the contact.

The contacts are subdivided into groups as follows.

1. <u>Submarine</u>

Trace length varies with aspect and speed. For a stationary target this length can change from 20 yards for a beam aspect to over 100 yards for a bow or stern aspect. When the submarine is moving, the length will approach the 130 yard limit, especially for the newer attack subs.

2. Whale, decoy

The trace length for both of these targets is very similar to a beam aspect submarine, usually less than 30 yards. From a direct bow or stern aspect, especially for whales, this length can extend into the interval between 30 and 70 yards; but the length should never exceed the 70 yard upper limit.

3. Pinnacle

The pinnacle presents a difficult contact to be classified in most respects and trace length is no exception. Generally characterized by a medium trace length similar to a bow or quarter aspect submarine, it none the less can also have a trace presentation similar to a beam aspect or direct bow/stern aspect submarine.

4. Ridge

The trace length of ridges and reefs is long, usually greater than 30 yards, and variable from transmission to transmission. Normally ridges fall into the interval between 30 and 70 yards but returns between 70 and 130 yards or even greater are not uncommon.

5. Fish, bottom

Following the trend of each sub-group in this category toward longer trace lengths, the most common length for these two contact types is in the interval between 70 and 130 yards.

This is easily understandable for bottom but why for fish? Since schools of fish are usually detected, and not individual fish, they give

irregular and long returns. Many separate contacts generate returns for each transmission and thus are displayed as long traces on the TRR.

Means, standard deviations and probability curves for trace length are shown in Appendix I.

Bearing Width. Bearing width is the angle subtended by the right and left edges of the PPI presentation of the contact.

This characteristic can be useful primarily because of the contacts it eliminates. The bearing width is divided into three intervals:

a. $0^{\circ} \leq \theta < 20^{\circ}$
b. $20^{\circ} \leq \theta \leq 30^{\circ}$
c. $30^{\circ} < \theta$

θ = bearing width in degrees and $0^{\circ} < \theta \leq 360^{\circ}$

The largest bearing width a submarine normally presents is in the interval between 20 and 30 degrees. This occurs at or near a beam aspect due to the larger portion of target length that is perpendicular to the sound beam. As the aspect changes toward either bow or quarter the bearing width decreases and moves into the interval less than 20 degrees. Contacts whose bearing width is greater than 30 degrees generally consist of bottom or ridges, and thus a wide bearing width is helpful in eliminating these types from consideration as possible submarines.

There are four subsets of contacts.

1. Submarine

Three probability curves are used to generate submarine bearing width. They are described in Table 5. The true aspect angle of the contact is α, μ is the mean of the probability distribution and σ its standard deviation. The actual curves are in Appendix I.

Table 5

Submarine Bearing Width Intervals

Interval	Mean	Standard Deviation
$70° \leq \alpha \leq 110°$ $250° \leq \alpha \leq 290°$	$\mu = 0$	$\sigma = .86$
$350° \leq \alpha \leq 10°$ $170° \leq \alpha \leq 190°$	$\mu = 0$	$\sigma = .73$
$10° < \alpha < 70°$ $110° < \alpha < 170°$ $190° < \alpha < 250°$ $290° < \alpha < 350°$	$\mu = 0$	$\sigma = .608$

2. Bottom, ridge, fish

Again fish may seem out of place, but schools of them tend to spread over large areas and can give an extremely wide pip on the PPI. Multiple pips also result from all three contacts in this subset, and this fact tends to widen the bearing width if these individual pips are close together.

3. Whale, decoy

The bearing width of these contacts is very similar in appearance to bow or quarter aspect submarines. They are characterized by a

narrow pip, usually less than 20 degrees in width. They seldom present a pip as wide as 30 degrees and never over this figure.

4. Pinnacle

Bearing width for pinnacles is much like a beam aspect submarine but can easily extend over 30 degrees or be less than 20 degrees. This distribution is different from others in the entire contact set because of the large standard deviation of the probability curve, $\sigma = 1.91$.

III. DISCUSSION OF RESULTS

A. Classification Equation

The weighting equation used for contact classification is:

$$WT = 1.0\,(\text{Doppler}) + .5\,(\text{Aspect}) + .5\,(\text{Edge}) + .5\,(\text{Trace}) + .1\,(\text{Bearing}) + 1.2\,(\text{Correlation})$$

The coefficients of this equation reflect the relative significance of each characteristic. As is the case in actual practice the correlation of characteristics is considered most important, closely followed by consistency of doppler. Aspect, edge alignment and trace length come next in importance and bearing width is the least useful of all the characteristics.

Any contact, except whales, that receives a value greater than or equal to 26.6 points from the weight equation is classified as possible submarine. Whales require a total greater than or equal to 28.4 points for classification as possible sub. From a sample of 2656 contacts, a 73 per cent overall correct classification was obtained when the above cutoffs were used.

Unfortunately whales cannot be classified by the same cutoff point as the other six contact types. The main reason for this is that the standard deviation of the submarine contacts is larger than that of the whale for every contact characteristic while the average value of each characteristic is approximately equal. No form of the weight equation could be found that would give a wide enough

difference between submarine and whale totals to give the correct classification percentage for these two contacts and also allow proper classification of the remaining contacts. Thus two cutoffs are required.

It is felt that a second reason for having to use two cutoff points is the small number of transmissions, five, used to determine classification. This prevents the buildup of a larger point differential in the correlation check where the submarine has a marked advantage over the other contacts. But the use of a large number of pings would defeat the purpose of a wartime cruising situation, which is a basic assumption of the model.

B. Sensitivity Analysis

A sensitivity analysis was conducted on the two areas of this study that were formulated from the author's experience rather than from actual data. These are the correlation matrices and the characteristic generating curves.

A new set of correlation matrices were devised in which only strict correlation was awarded points. Borderline cases such as up doppler vs. beam aspect were given no correlation although a slight possibility of correlation does exist in some instances. This lowered the mean value of the correlation characteristic of the submarine from 9.8 to 8.9 points, but it also lowered this characteristic for all

other contacts by an equal or greater amount. Thus the relative effect on classification was no different, and whales still had to be classified separately.

The effect of the accuracy of the characteristic generating curves on contact classification was checked by the following method. The same weight equation and cutoff values given in the previous section were used. Then the area between $\pm 1\sigma$ of each normally distributed curve was decreased by .05. This increased the variance of each characteristic by adding probability to the tails of the curves and thus increased the probability of operator error. Each contact was then rerun through the model, and the ratio of the change in the average weight value to the original weight value was computed and compared against this ratio for submarines. Although to obtain the same percentage of correct classification (73%) with these new curves, the cutoff points had to be lowered with the relative values about the cutoff points remaining almost constant.

Therefore, although the values of the contacts varied with these changes in the input data, they remained in approximately the same relative position before and after the change.

C. Recommendations

This program in its present form can be used in an ASW war game to provide the same degree of uncertainty of contact classification that actually exists in the fleet today.

If the existing group of sonar contact characteristics is investigated and the ones most useful to the human operator defined in a quantitative manner, then it would be possible to undertake a data collection effort to determine operator response to those useful characteristics on an individual transmission basis. With this list of characteristics and data an analytical model, similar to this simulation, could be developed to assist in training sonar operators by setting forth a list of classification rules to follow. Perhaps this analytical model could even be of assistance to shipboard personnel in this now tricky and complex field of sonar contact classification.

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APPENDIX I

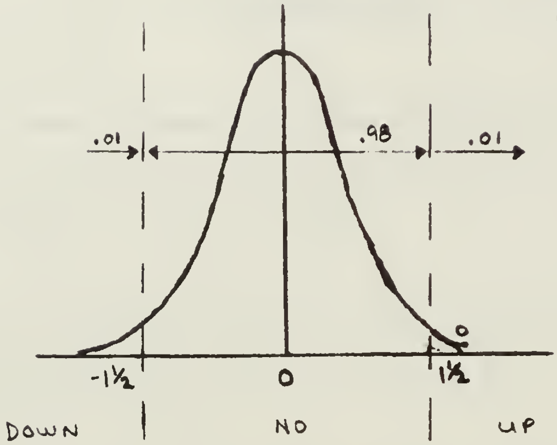
Characteristic Curves & Comparison Matrices

[redacted]

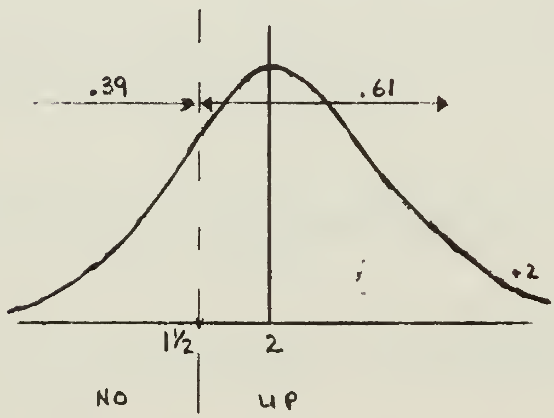
Doppler

Submarine
Whale
Fish
Decoy

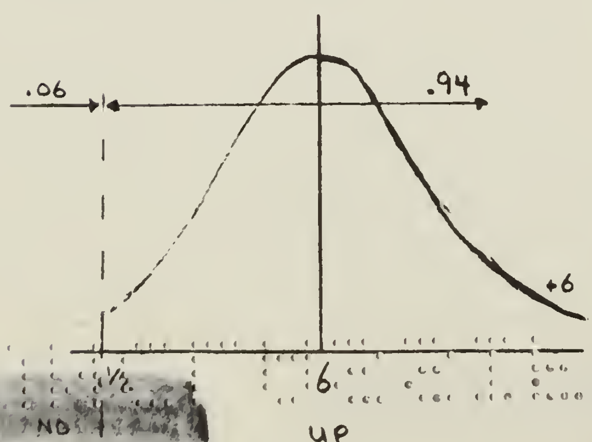
SLOB = 0 KTS
$\mu = 0$
$\sigma = .731$



$0 < |SLOB| \leq 4$ KTS.
$|\mu| = 2$
$\sigma = 3.92/|SLOB|$



$4 < |SLOB| \leq 8$ KTS
$|\mu| = 6$
$\sigma = 18/|SLOB|$



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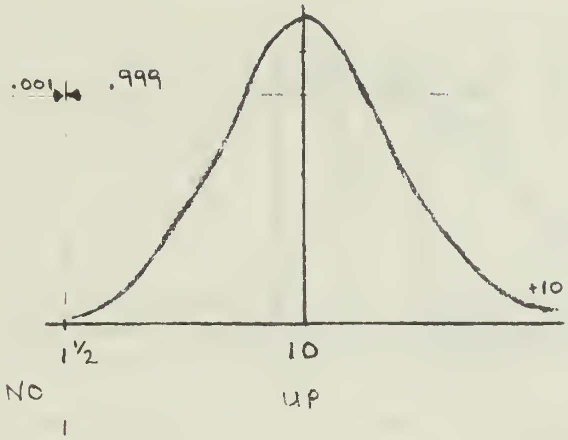
8 KTS < |SLOBE|

$|\mu| = 10$

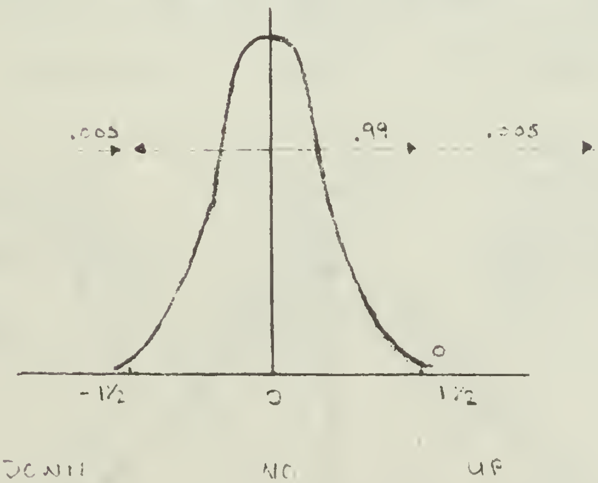
$\sigma = 275/(\text{SLOBE})^2$



BOTTOM

$\mu = 0$

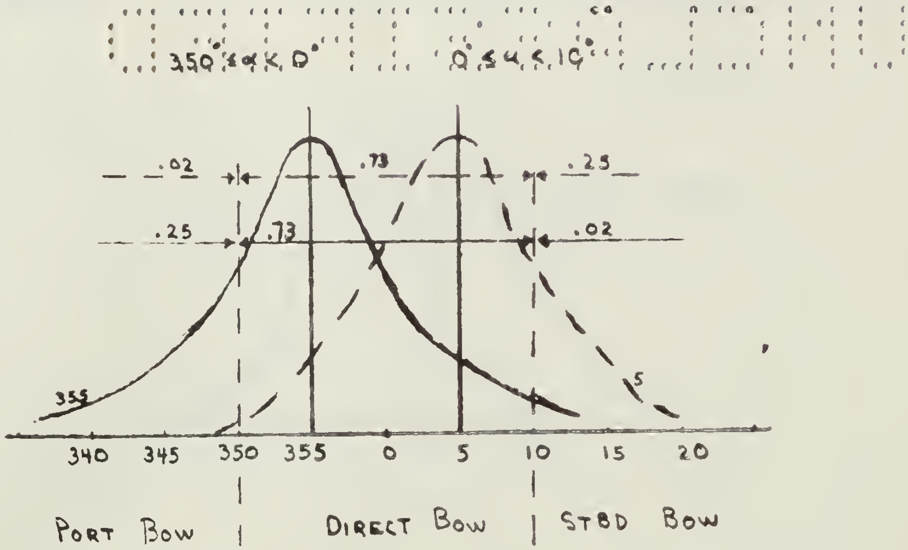
$\sigma = .645$

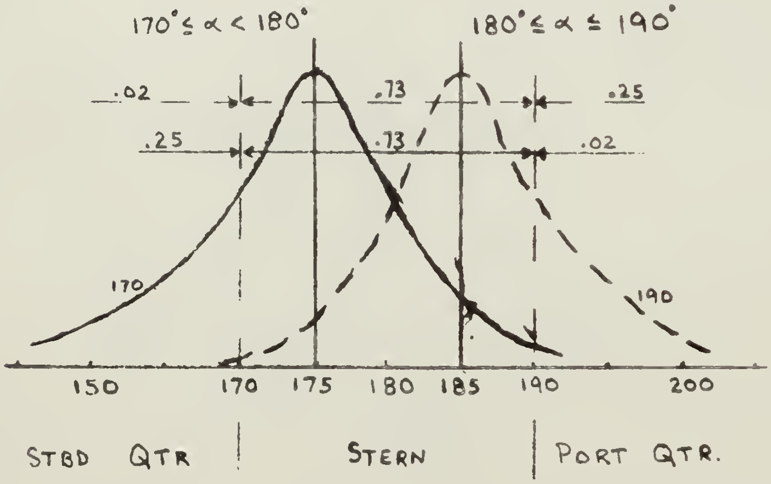


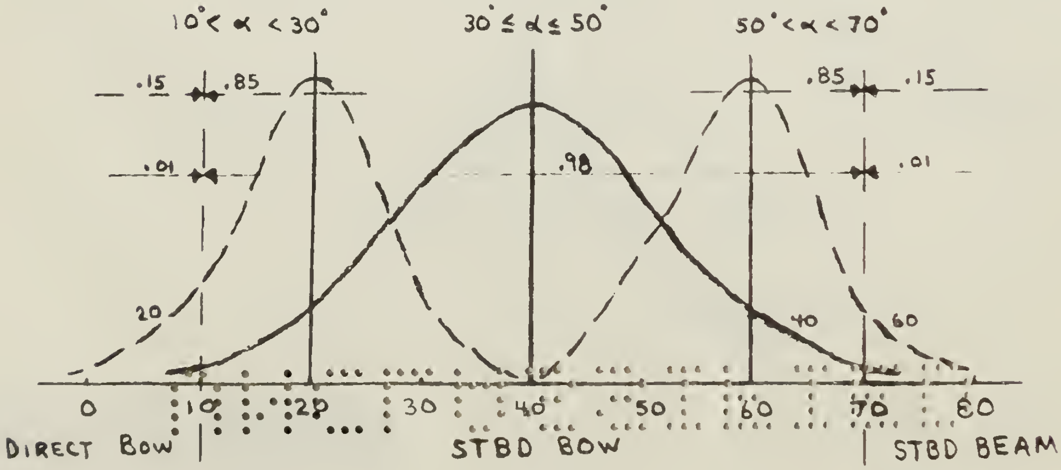
[redacted]

ASPECT

SUB
WHALE
PINNACLE







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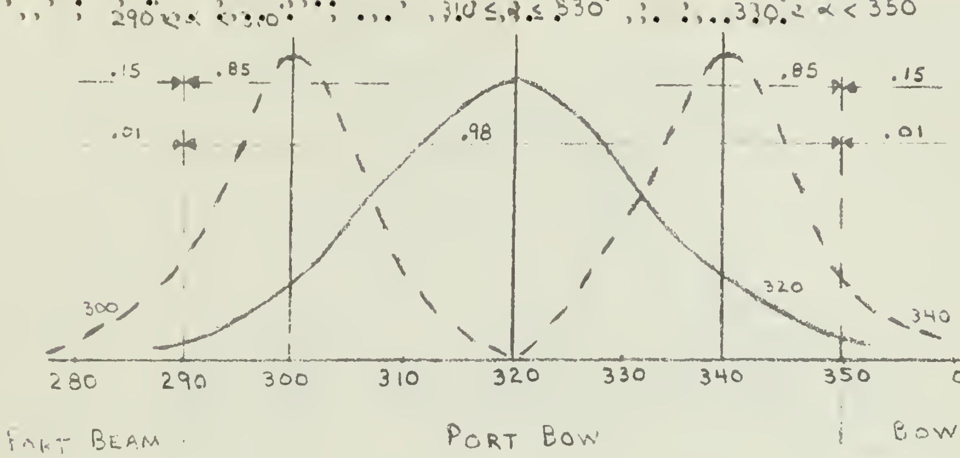

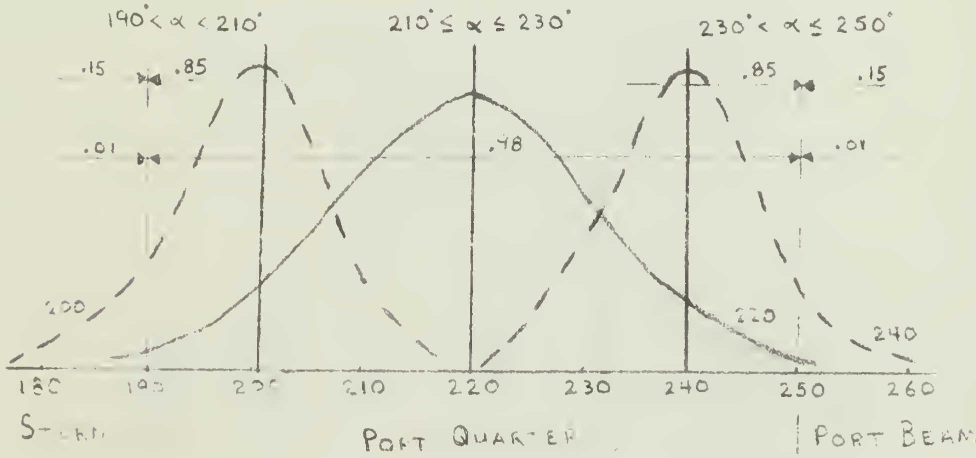

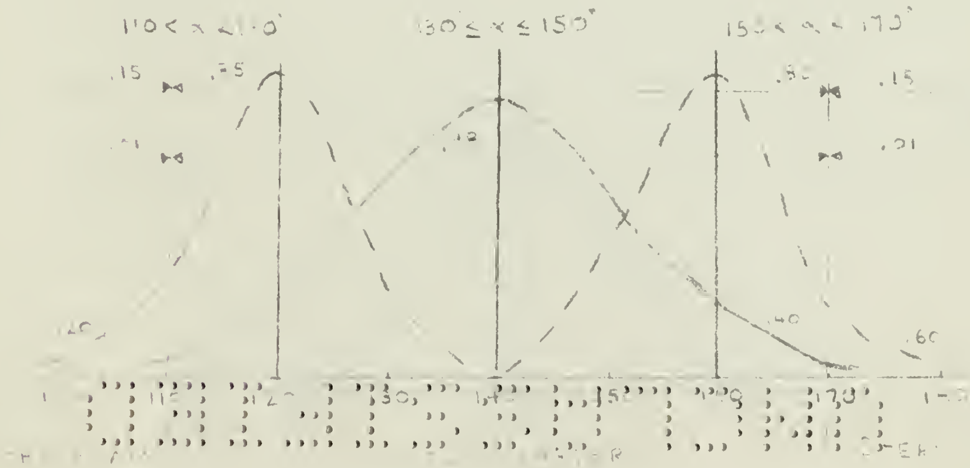

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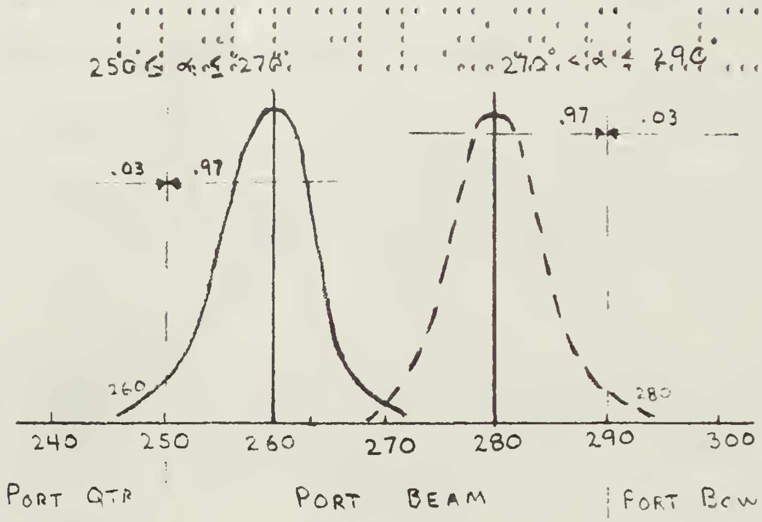
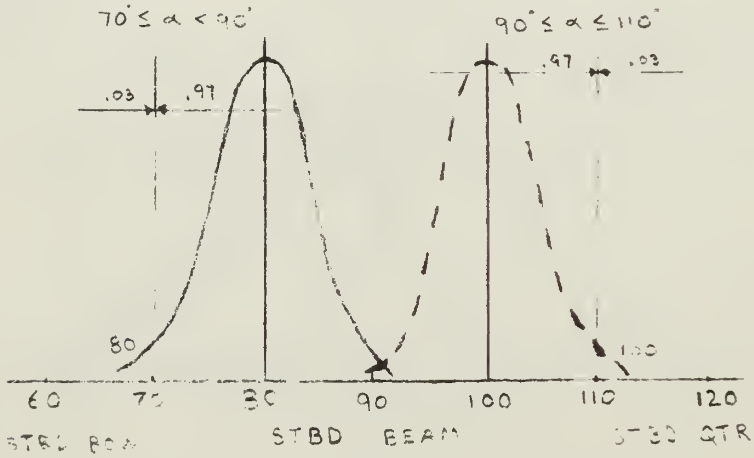
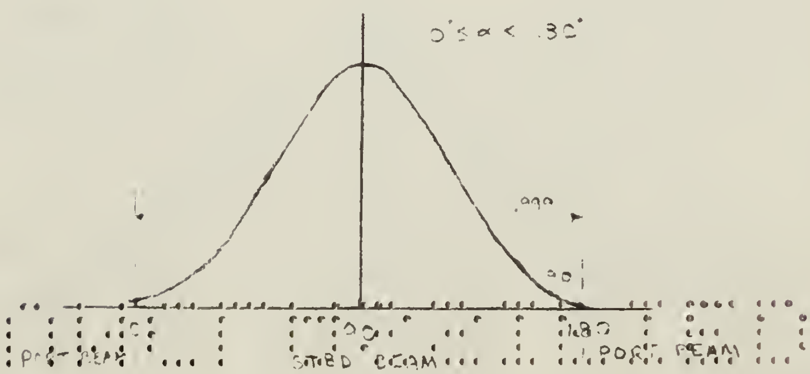




Decoy



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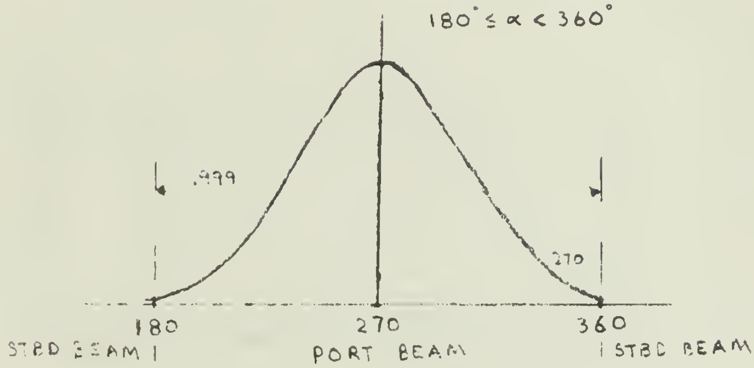
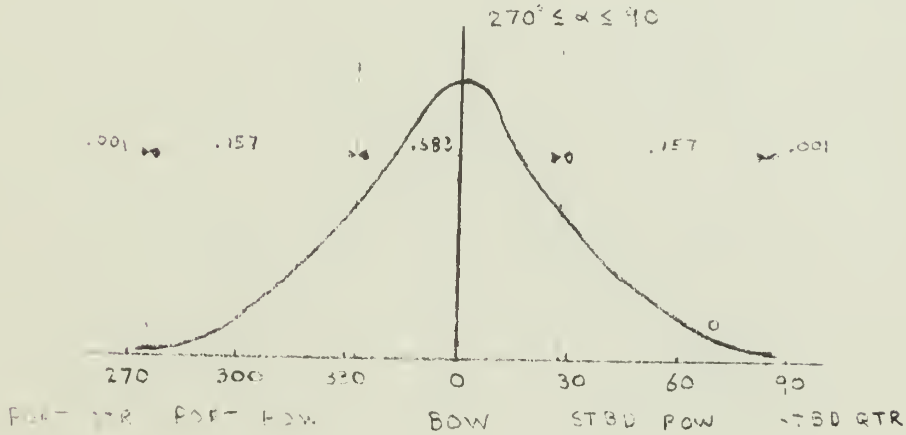
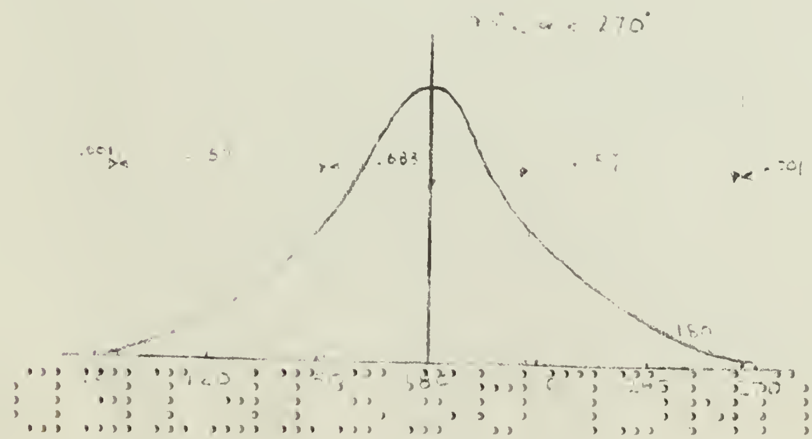
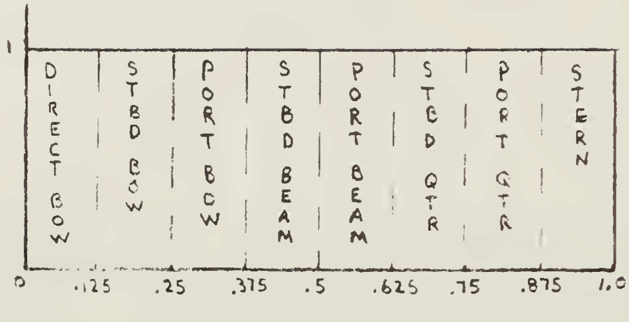

180° ≤ α < 360°
.999
270
180
270
360
STBD BEAM
PORT BEAM
STBD BEAM

Fish


270° ≤ α ≤ 90
.001
.157
.683
.157
.001
0
270
300
330
0
30
60
90
BOW
STBD BOW
STBD QTR


270°
.001
.683
180

Bottom Ridge

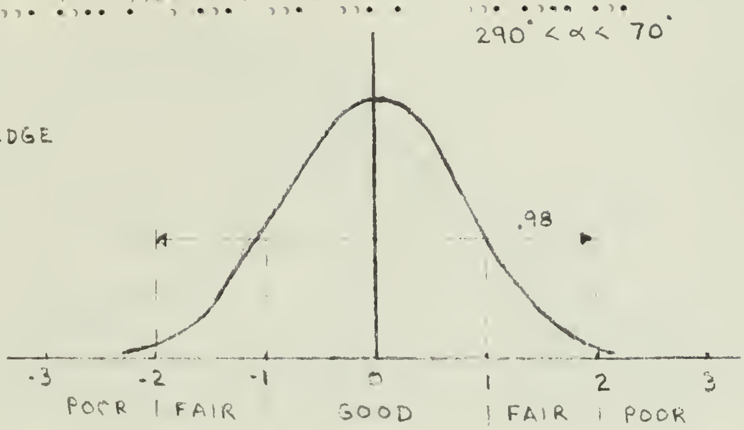


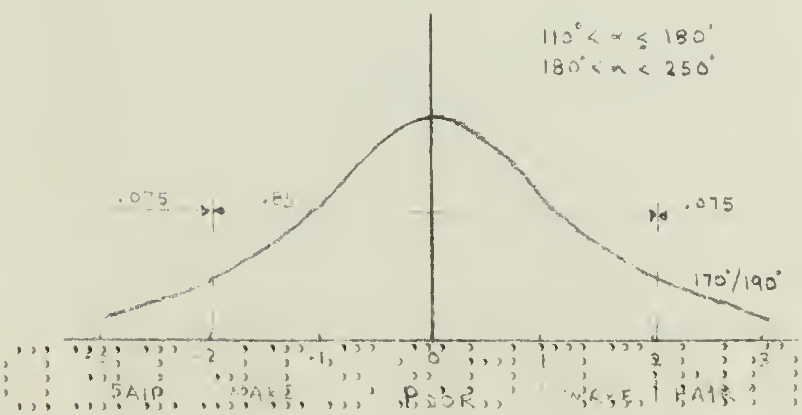
Uniform [0,1]

Edge Alignment

Sub

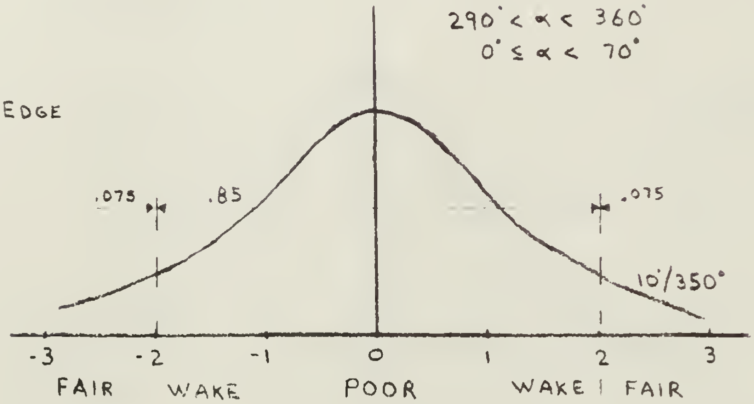
Left Edge

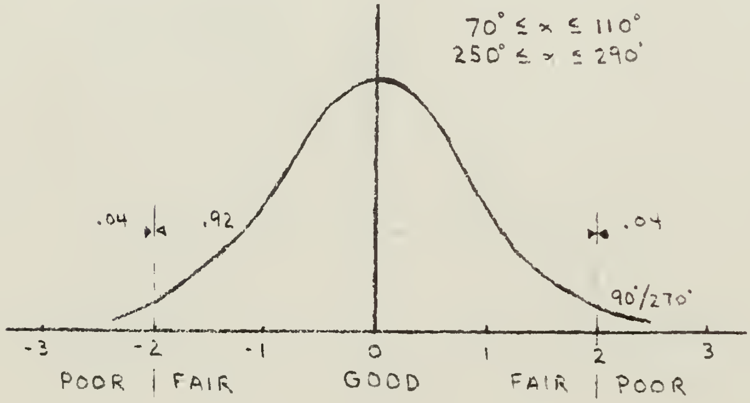


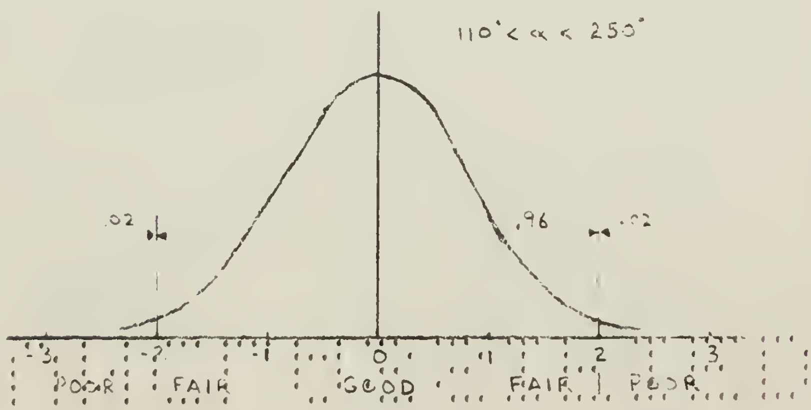


Sub

Right Edge







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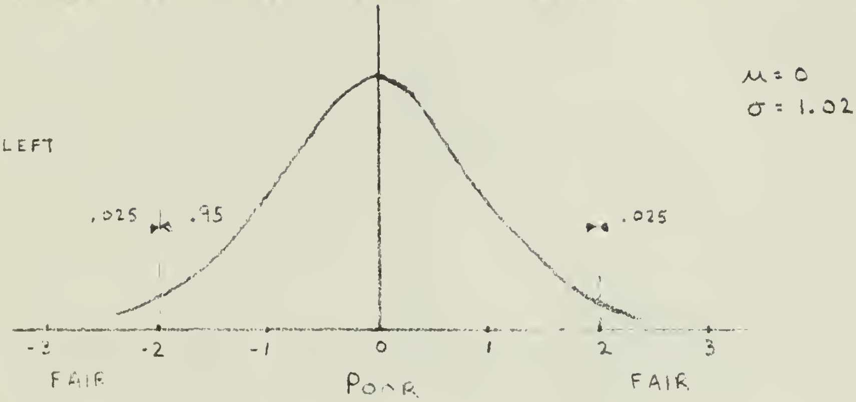
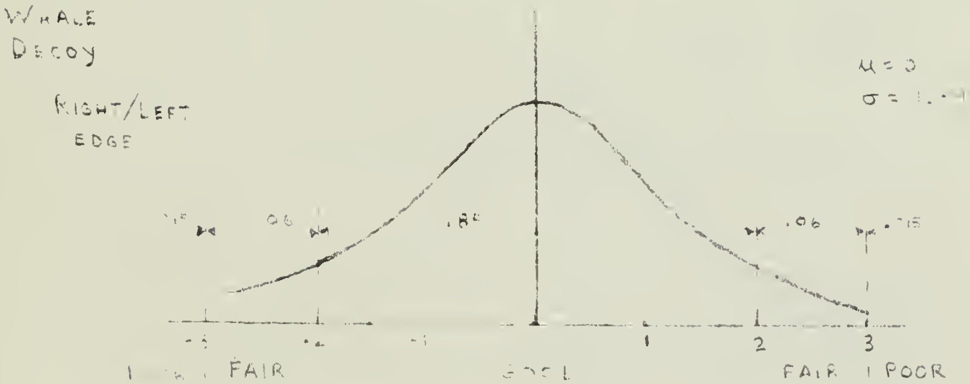
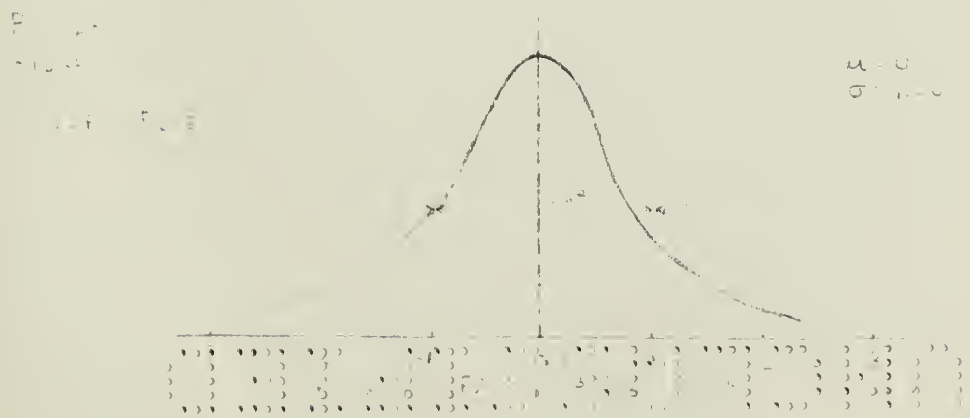
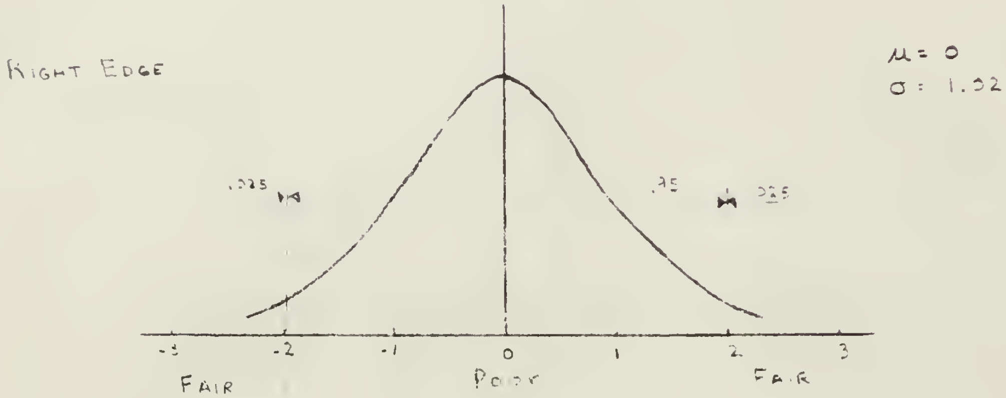




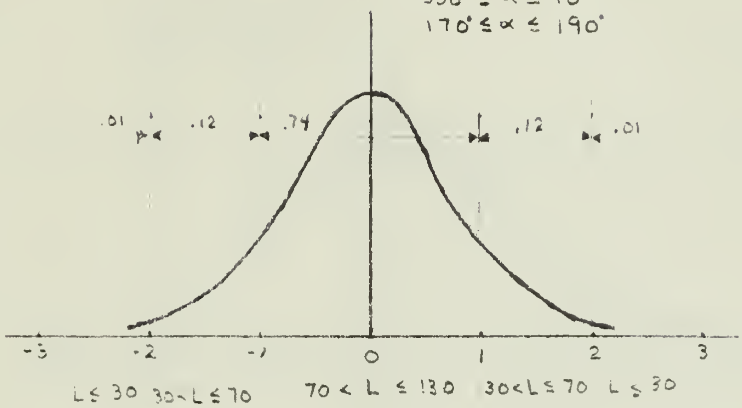



Right Edge
μ = 0
σ = 1.02
.025
.95
.025
-3
-2
-1
0
1
2
3
Fair
Poor
Fair

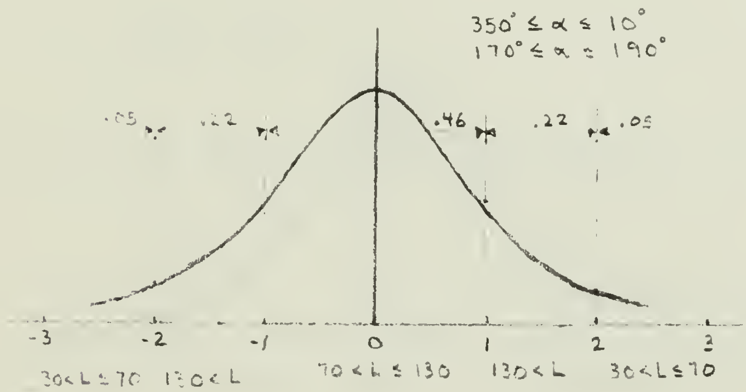
TRACE LENGTH
(L IN YDS)

Sub

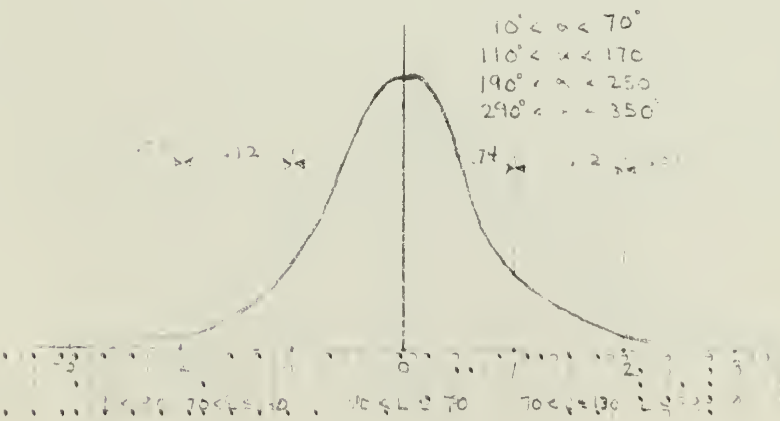
SLOPE = 0
$\mu = 0$
$\sigma = .86$

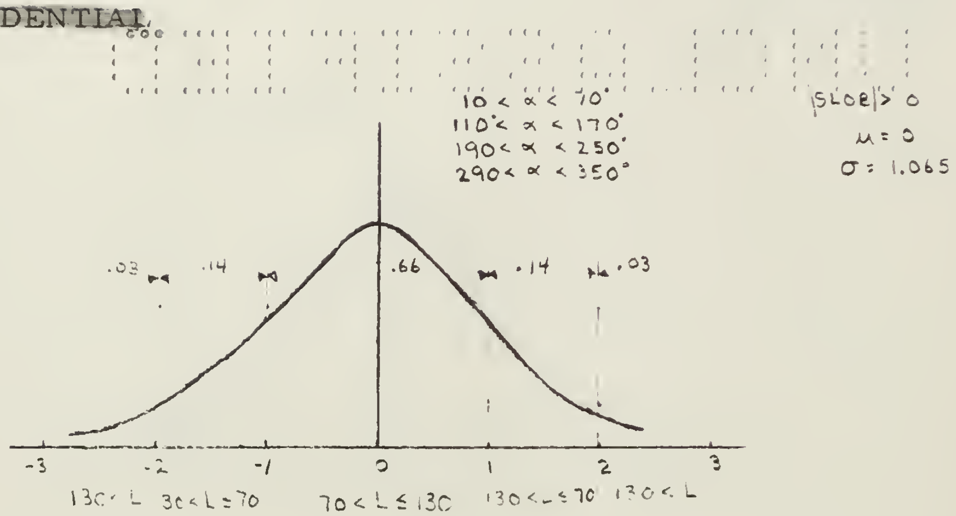


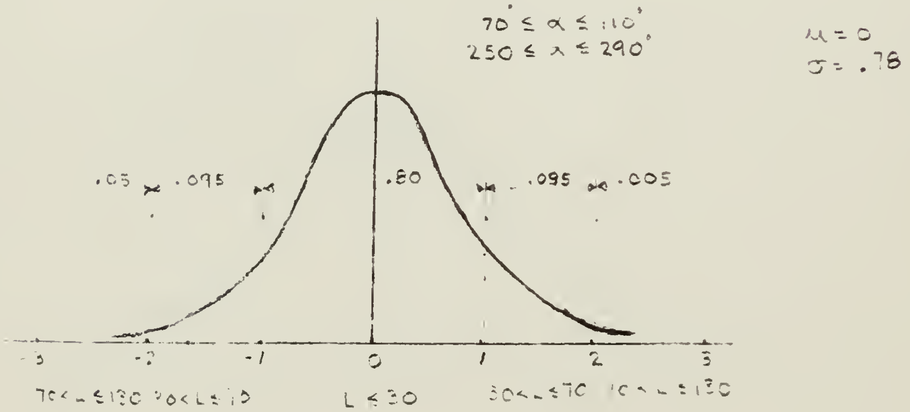
$|SLOPE| > 0$
$\mu = 0$
$\sigma = 1.215$

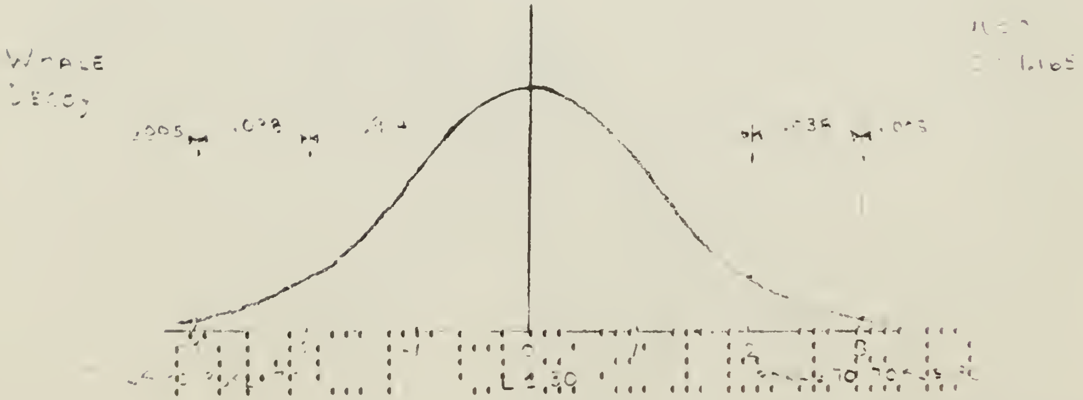


SLOPE
$\mu = 0$
$\sigma = .86$




10 < α < 70°
110° < α < 170°
190 < α < 250°
290 < α < 350°
|SLOPE| > 0
μ = 0
σ = 1.065
.03
.14
.66
.14
.03
-3
-2
-1
0
1
2
3
130 < L
30 < L ≤ 70
70 < L ≤ 130
30 < L ≤ 70
130 < L


70° ≤ α ≤ 110°
250 ≤ α ≤ 290°
μ = 0
σ = .78
.05
.095
.80
.095
.005
-1
0
1
2
3
L ≤ 30


WHALE
L ≤ 30

~~CONFIDENTIAL~~

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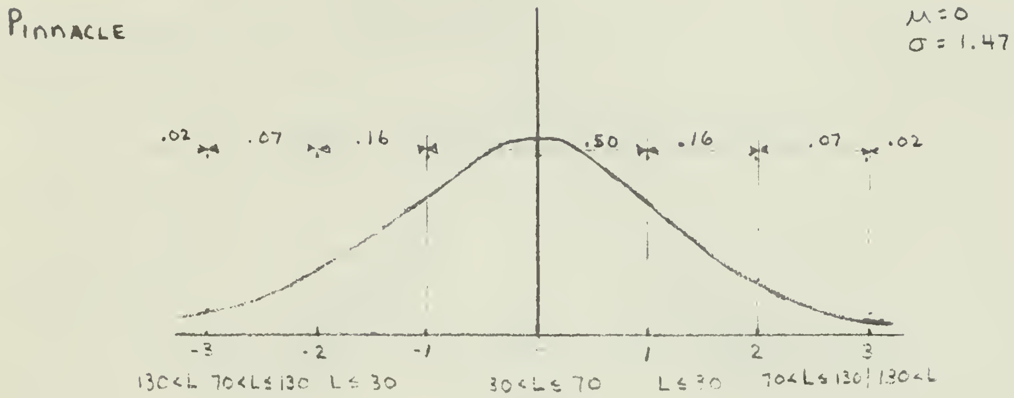

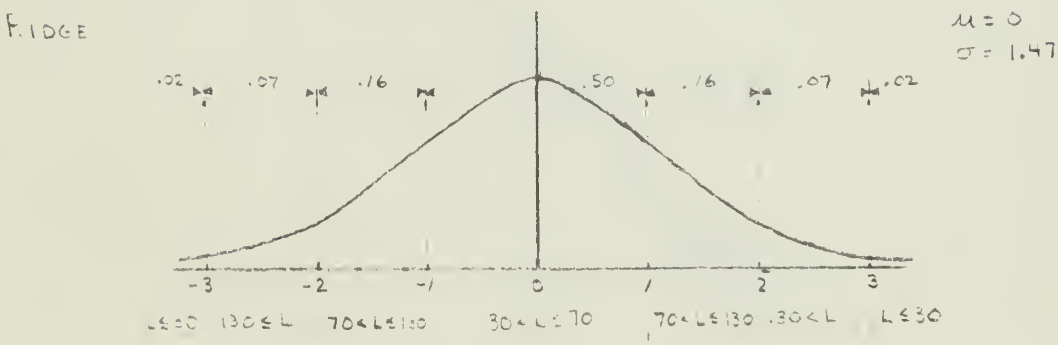

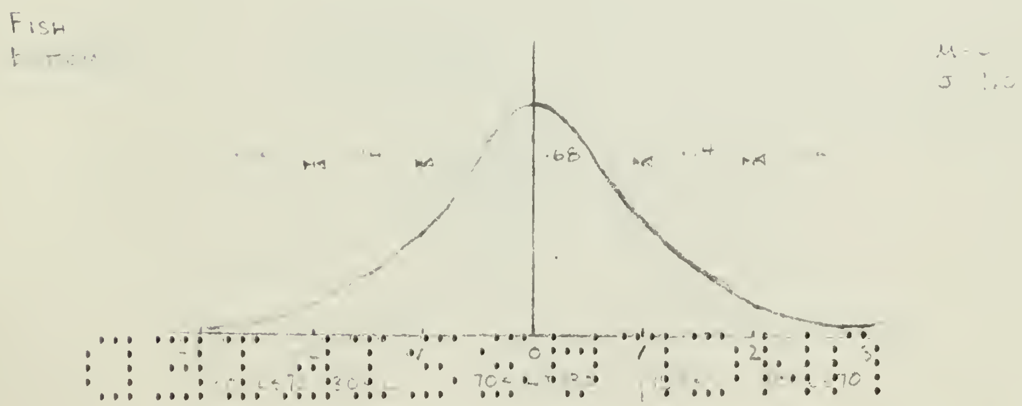

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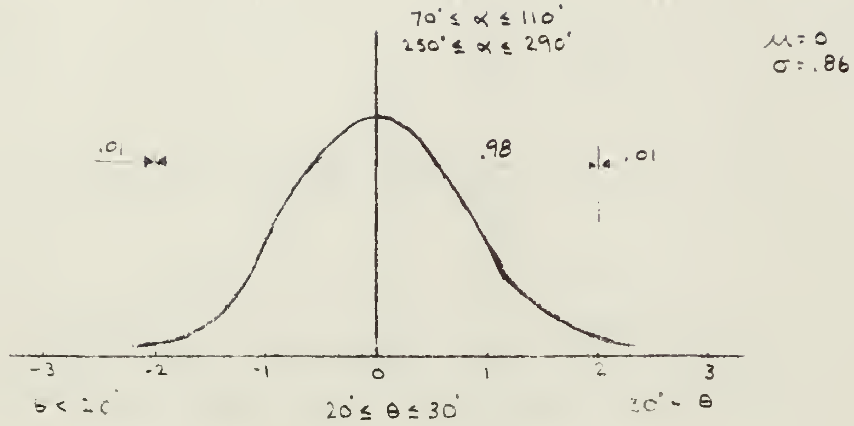
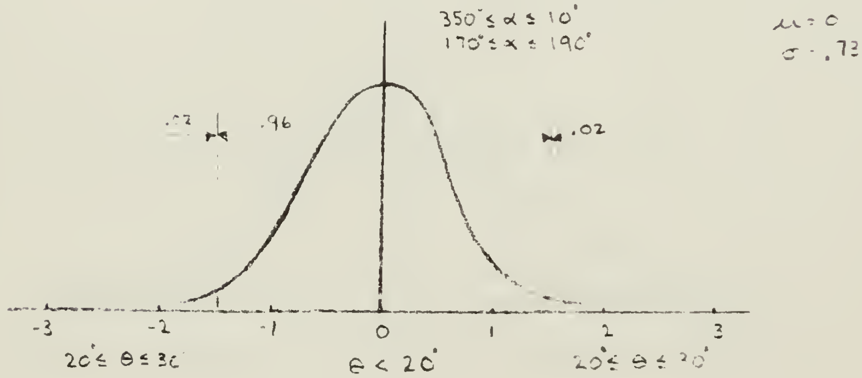
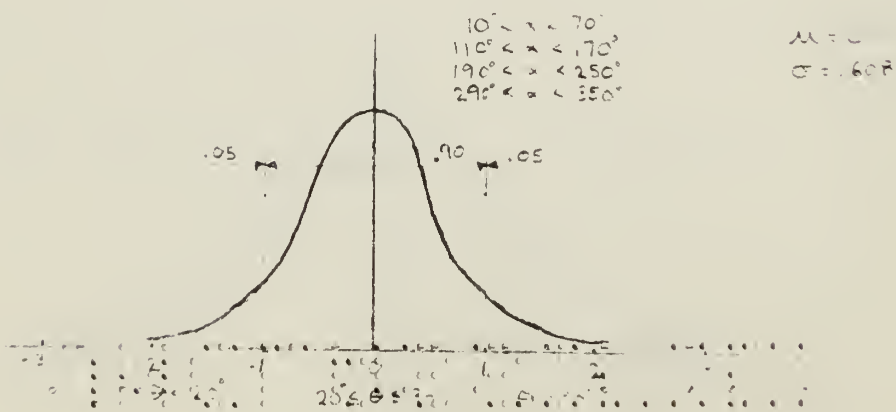
BEARING WIDTH

SUB

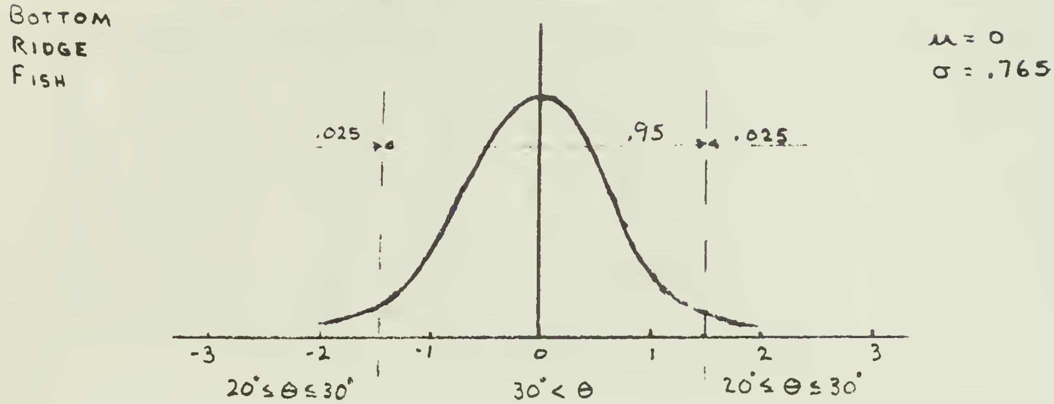


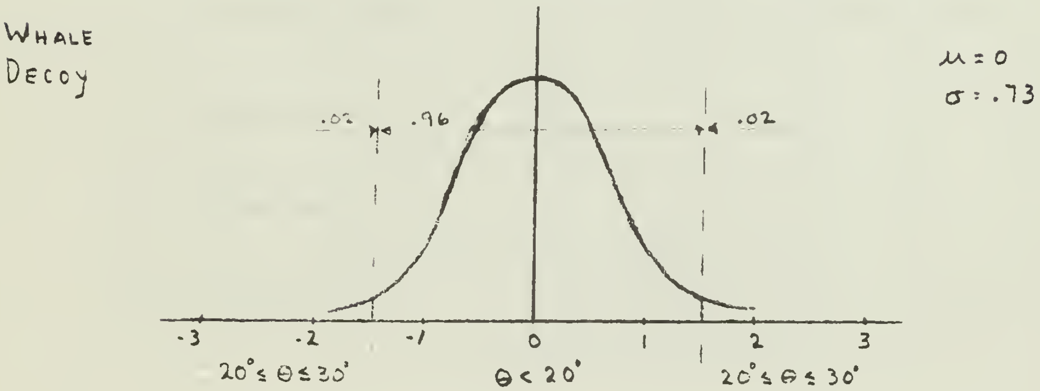


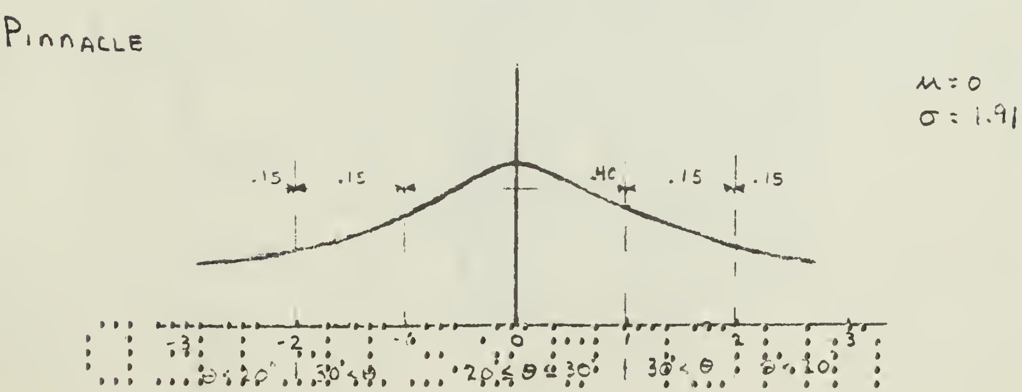


CONFIDENTIAL

UNCLASSIFIED







Doppler vs Aspect

	Direct Bow	Bow	Beam	Qtr	Stern
Up	2	2	1	0	0
No	0	1	2	1	0
Down	0	0	1	2	2

Doppler vs Trace Length

	L ≤ 30	30 < L ≤ 70	70 < L ≤ 130	L > 130
Up	0	1	2	0
No	2	1	0	0
Down	0	1	2	0

Doppler vs Left Edge Align.

	Good	Fair	Poor	Wake
Up	2	1	0	0
No	1	1	0	[illegible]
Down	0	1	2	[illegible]

Doppler vs Bearing Width

	$\theta < 20$	$20 \le \theta \le 30$	$\theta > 30$
Up	2	1	0
No	0	2	0
Down	2	1	0

Doppler vs Right Edge Align.

	Good	Fair	Poor	Wake
Up	[illegible]	1	[illegible]	3
No	1	1	0	0
Down	2	1	[illegible]	[illegible]

Aspect vs Left Edge Align

	Direct Bow	Bow	Beam	Qtr	Stern
Good	2	2	2	0	[illegible]
Fair	1	1	1	0	[illegible]
Poor	0	[illegible]	0	1	1
Wake	[illegible]	0	0	1	2

Aspect vs. Right Edge Align

	Dir Bow	Bow	Beam	Qtr.	Stern
Good	0	0	2	2	2
Fair	0	0	1	1	1
Poor	1	1	0	0	0
Wake	2	1	0	0	0

Aspect vs. Trace Length

	Dir Bow	Bow	Beam	Qtr.	Stern
$L \leq 30$	0	0	2	0	0
$30 < L \leq 70$	0	1	0	1	0
$70 < L \leq 130$	2	1	0	1	2
$L > 130$	0	0	0	0	0

Aspect vs Bearing Width

	Dir Bow	Bow	Beam	Qtr	Stern
$\theta < 20$	2	1	0	1	2
$20 \leq \theta \leq 30$	0	2	2	2	0
$\theta > 30$	0	0	0	0	0

APPENDIX II

Logic Flow Chart

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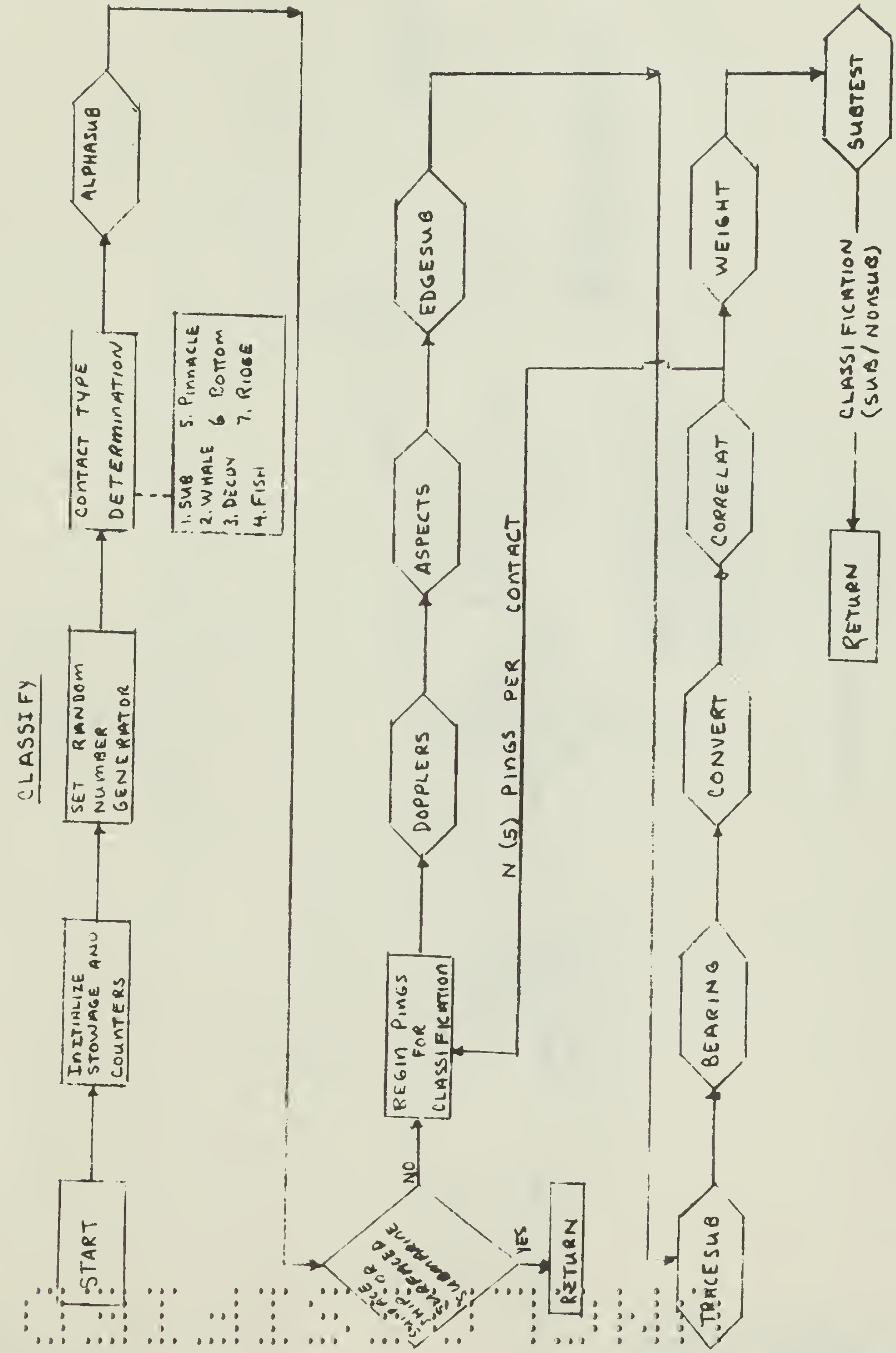

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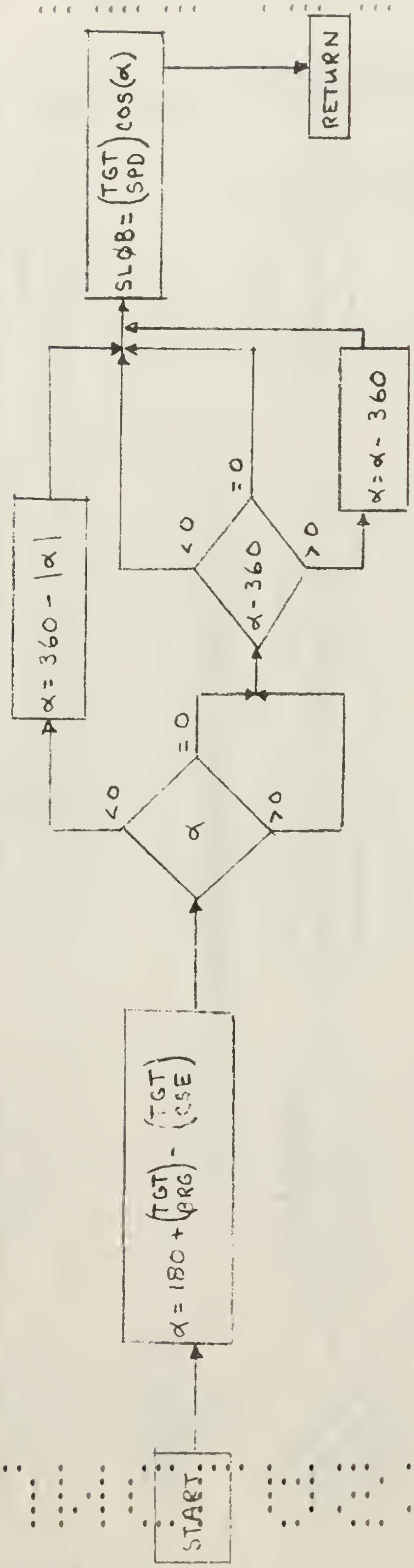

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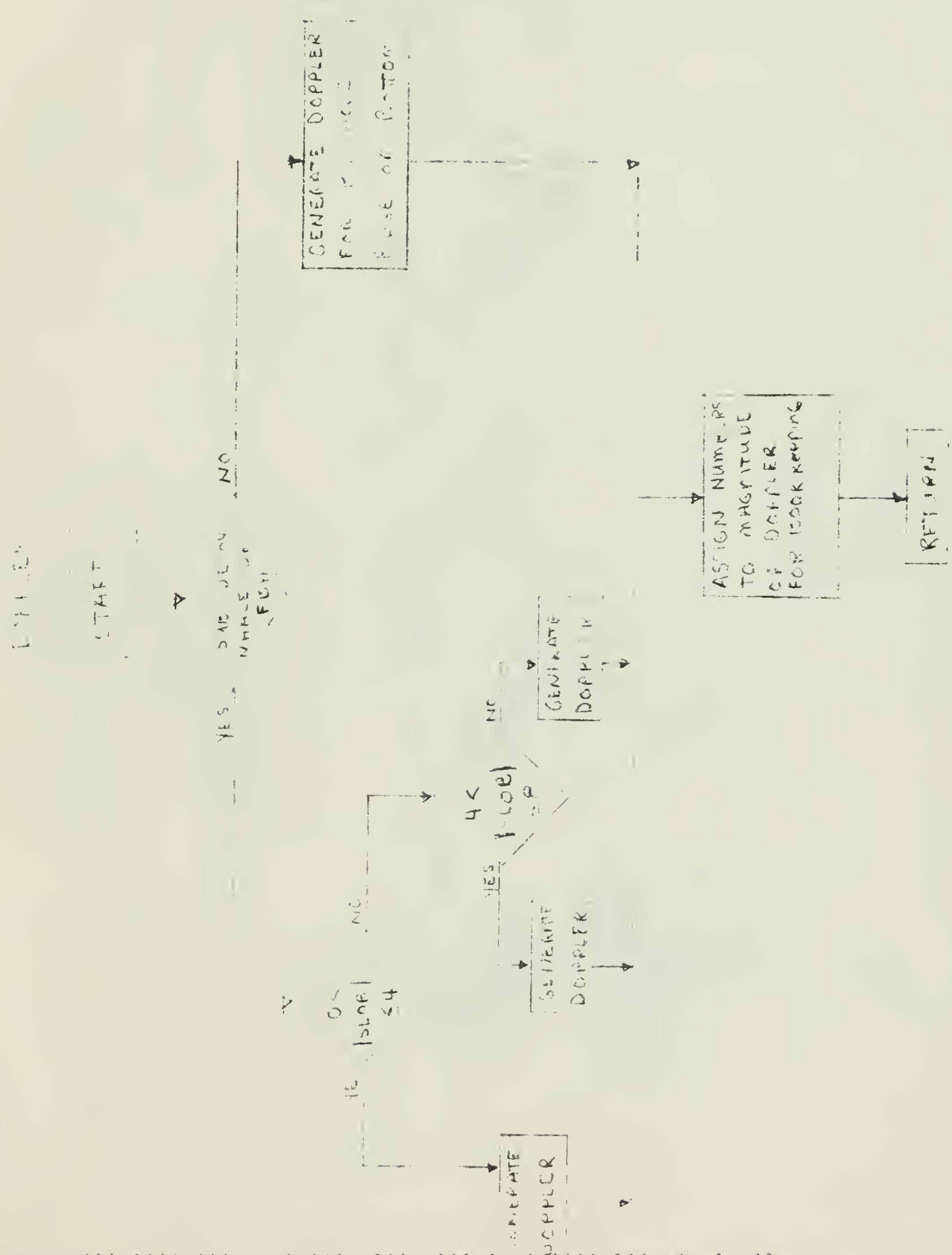
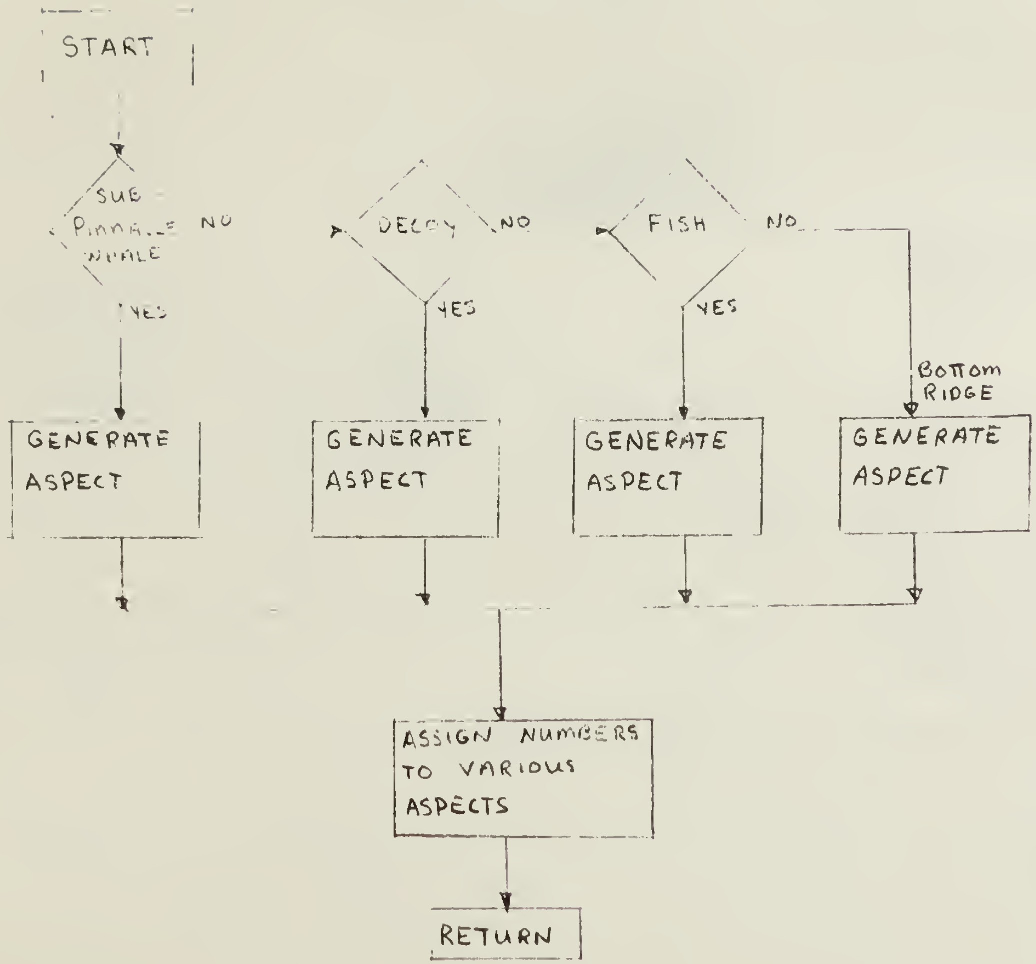

GENERATE DOPPLER
YES
NO
GENERATE DOPPLER
DOPPLER
ASSIGN NUMBER
TO MAGNITUDE
OF DOPPLER
FOR BOOKKEEPING

ASPECTS


START
SUB PINNACLE WHALE
NO
YES
GENERATE ASPECT
DECOY
NO
YES
GENERATE ASPECT
FISH
NO
YES
GENERATE ASPECT
BOTTOM RIDGE
GENERATE ASPECT
ASSIGN NUMBERS TO VARIOUS ASPECTS
RETURN

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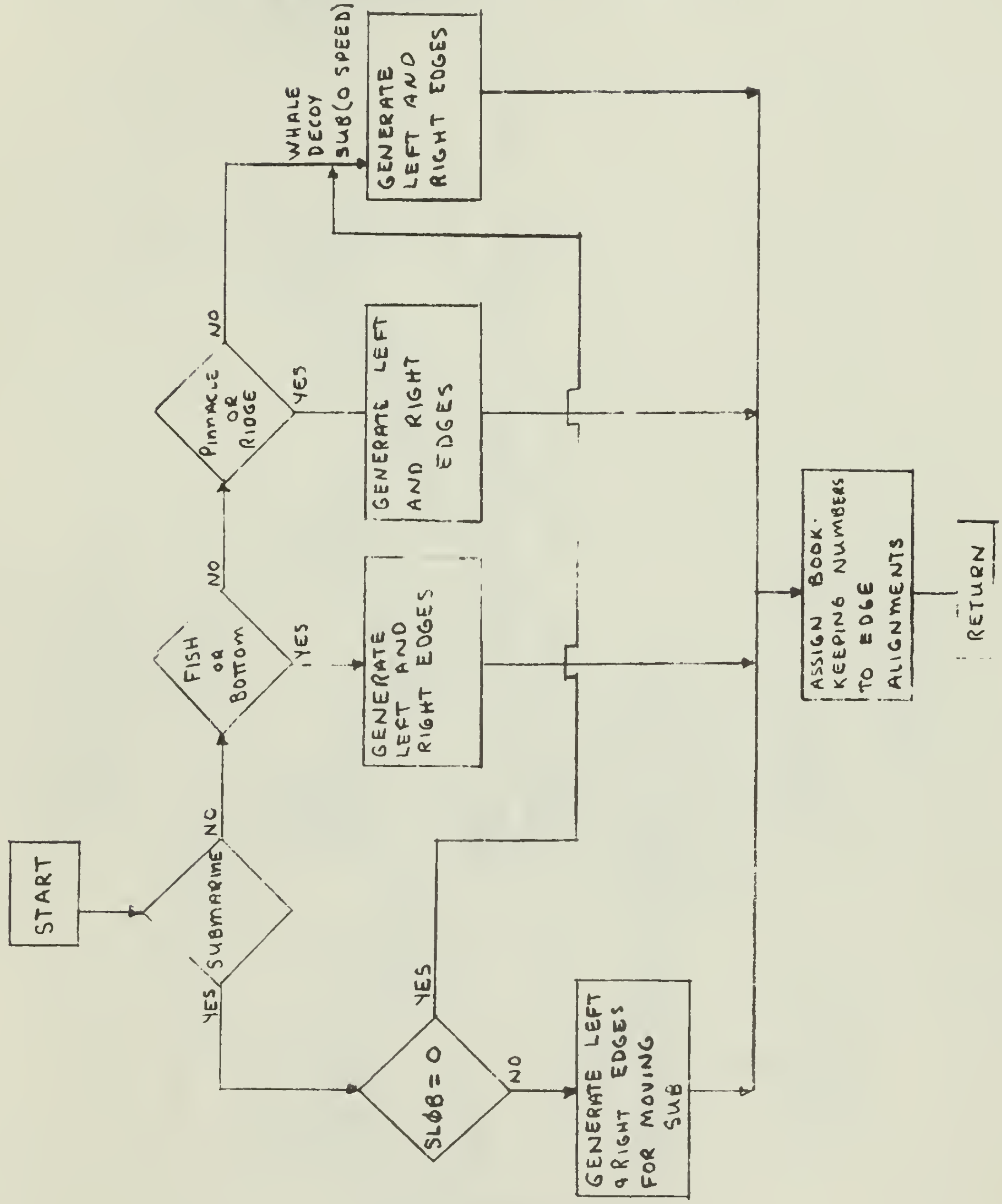
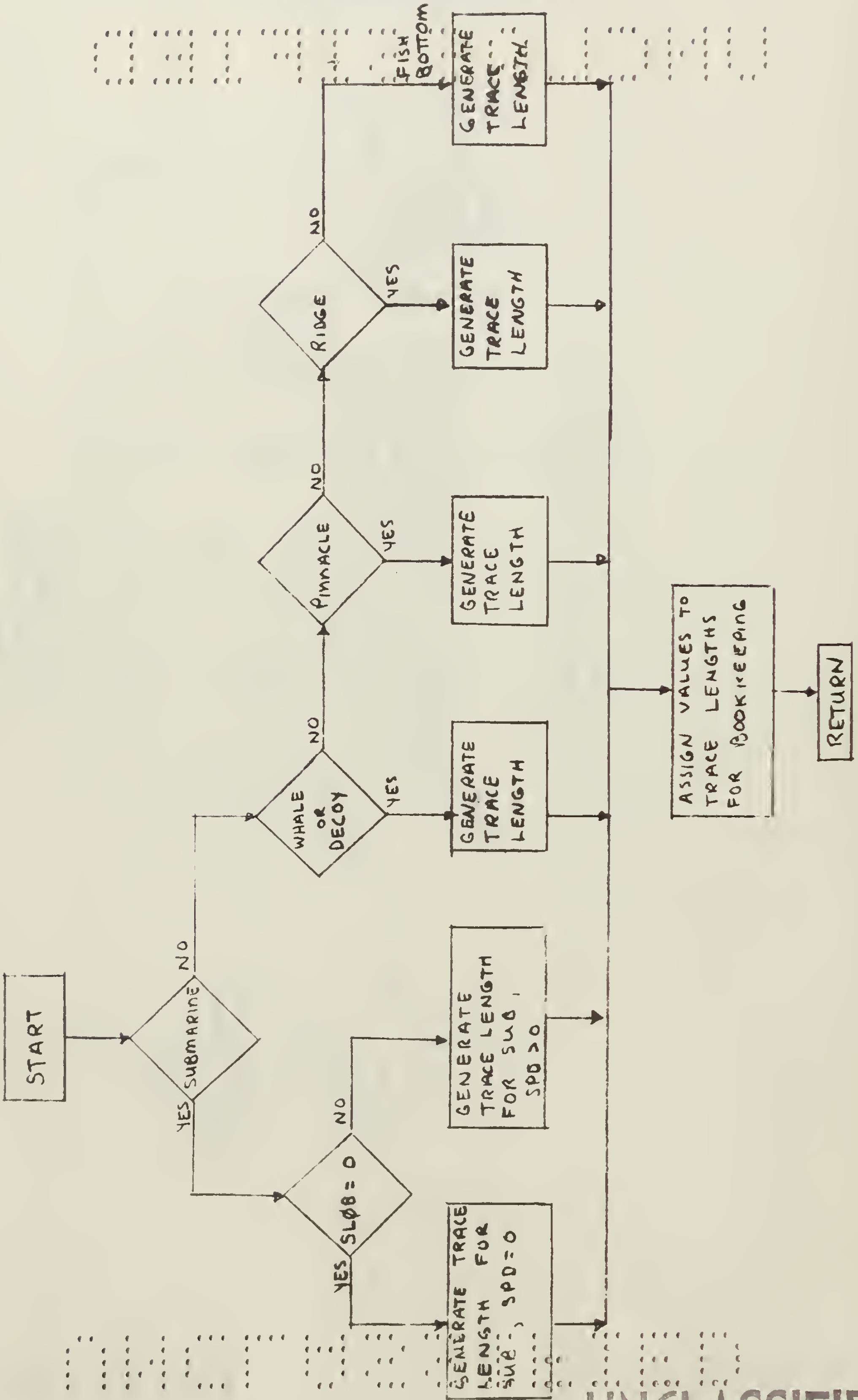
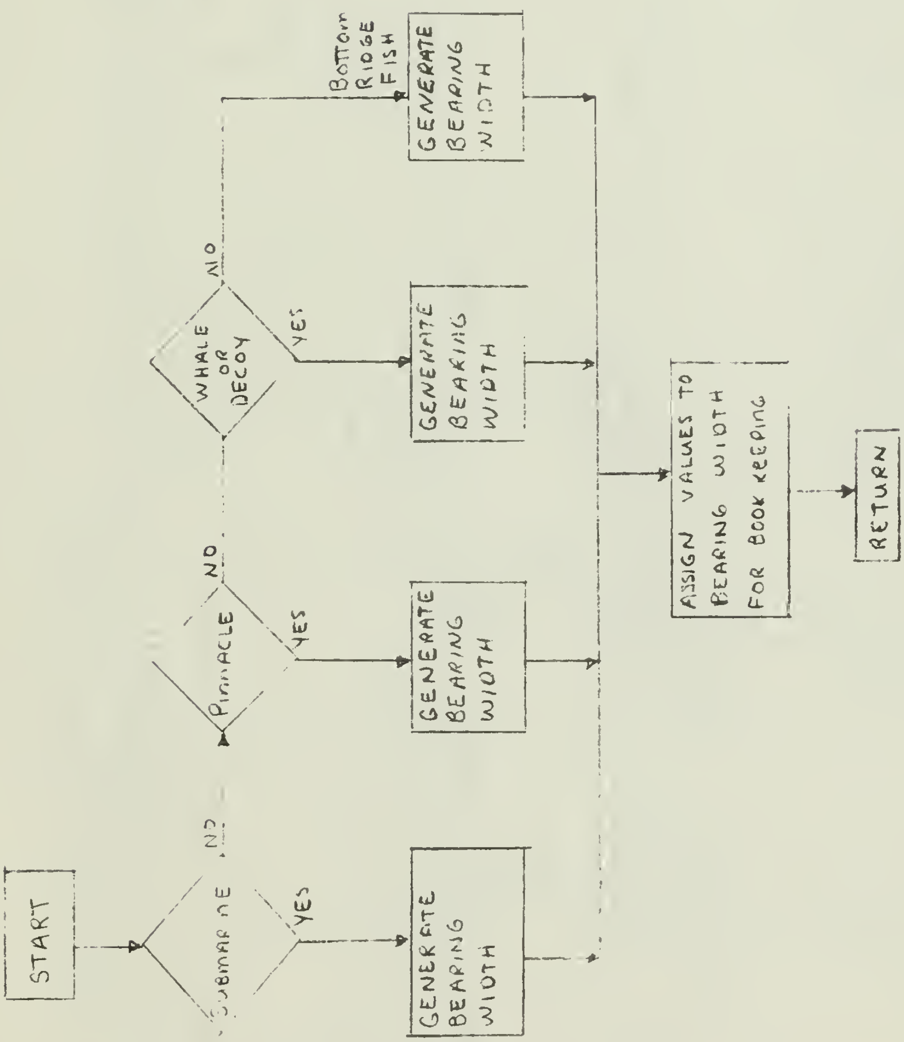
EDGE



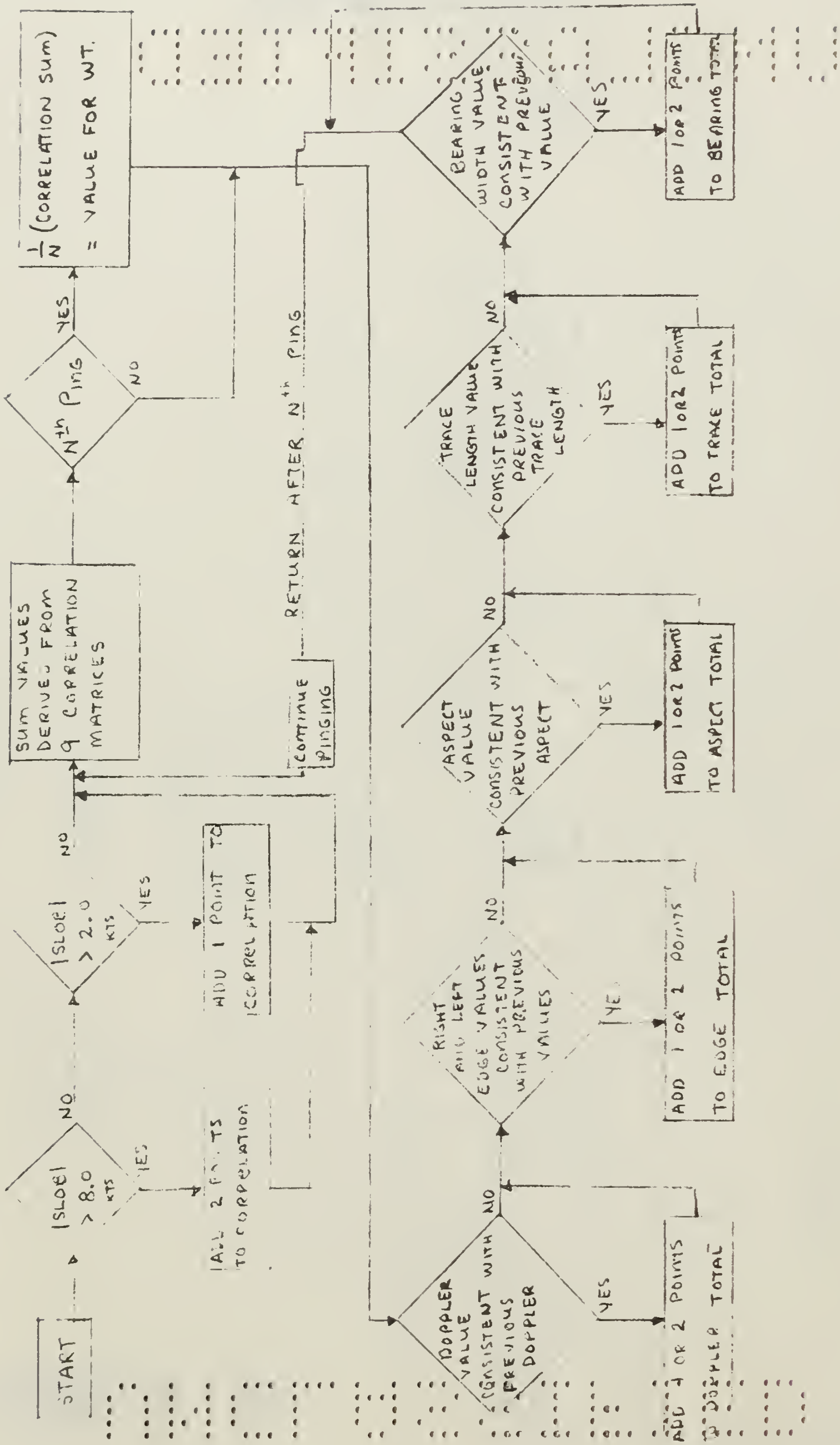
TRACESUE


START
SUBMARINE
YES
NO
SLØB = 0
YES
NO
GENERATE TRACE LENGTH FOR SUB, SPD = 0
GENERATE TRACE LENGTH FOR SUB, SPD > 0
WHALE OR DECOY
YES
NO
GENERATE TRACE LENGTH
PINNACLE
YES
NO
GENERATE TRACE LENGTH
RIDGE
YES
NO
GENERATE TRACE LENGTH
FISH BOTTOM
GENERATE TRACE LENGTH
ASSIGN VALUES TO TRACE LENGTHS FOR BOOKKEEPING
RETURN

BEARING


START
SUBMARINE
YES
NO
GENERATE BEARING WIDTH
PINNACLE
YES
NO
GENERATE BEARING WIDTH
WHALE OR DECOY
YES
NO
GENERATE BEARING WIDTH
BOTTOM RIDGE FISH
GENERATE BEARING WIDTH
ASSIGN VALUES TO BEARING WIDTH FOR BOOK KEEPING
RETURN

CORRELAT


START
|SLOE| > 8.0 KTS
YES
NO
ADD 2 POINTS TO CORRELATION
|SLOE| > 2.0 KTS
YES
NO
ADD 1 POINT TO CORRELATION
SUM VALUES DERIVED FROM 9 CORRELATION MATRICES
Nth PING
YES
NO
1/N (CORRELATION SUM) = VALUE FOR WT.
CONTINUE PINGING
RETURN AFTER Nth PING
DOPPLER VALUE CONSISTENT WITH PREVIOUS DOPPLER
ADD 1 OR 2 POINTS TO DOPPLER TOTAL
RIGHT AND LEFT EDGE VALUES CONSISTENT WITH PREVIOUS VALUES
ADD 1 OR 2 POINTS TO EDGE TOTAL
ASPECT VALUE CONSISTENT WITH PREVIOUS ASPECT
ADD 1 OR 2 POINTS TO ASPECT TOTAL
TRACE LENGTH VALUE CONSISTENT WITH PREVIOUS TRACE LENGTH
ADD 1 OR 2 POINTS TO TRACE TOTAL
BEARING WIDTH VALUE CONSISTENT WITH PREVIOUS VALUE
ADD 1 OR 2 POINTS TO BEARING TOTAL

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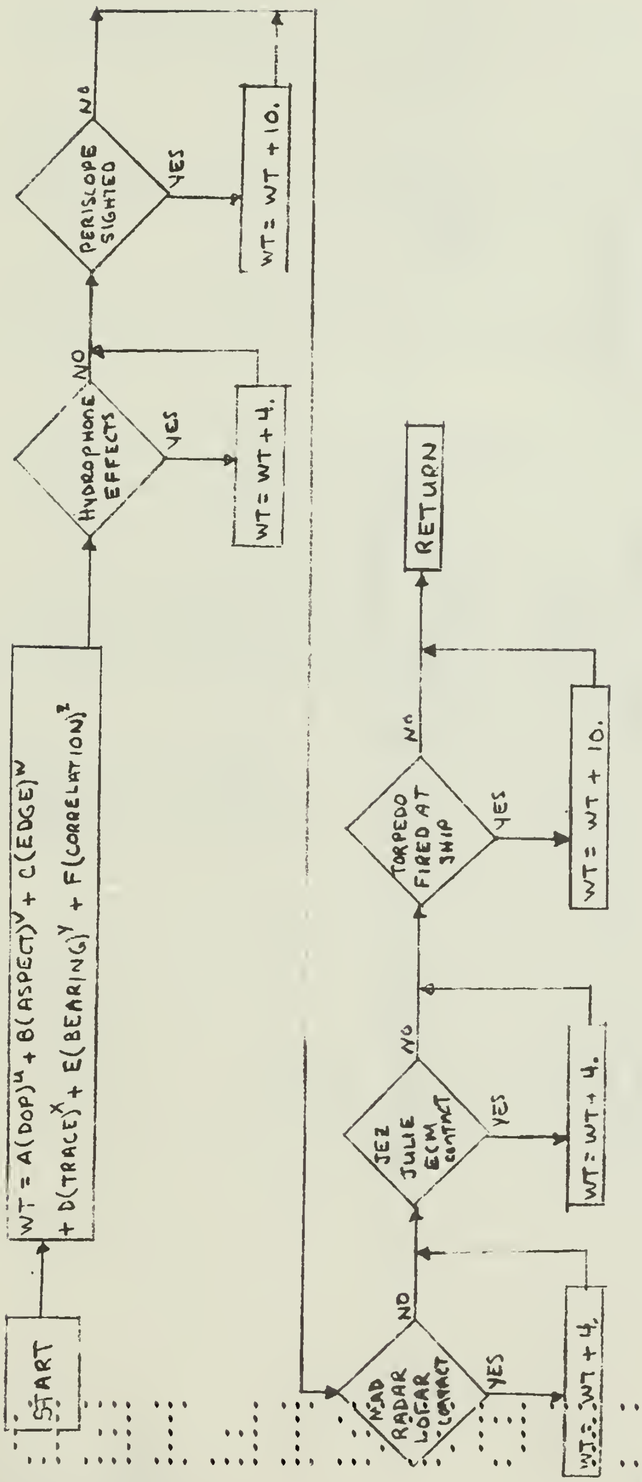
WEIGHT



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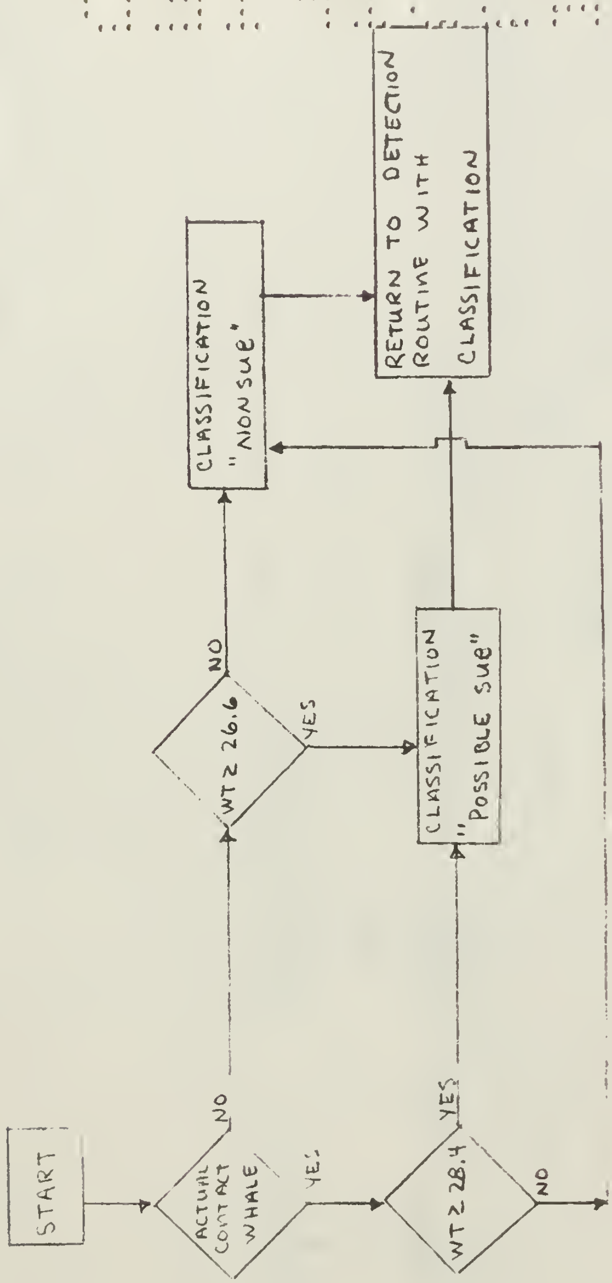
START
ACTUAL CONTACT WHALE
NO
YES
WT ≥ 28.4
YES
NO
WT ≥ 26.6
NO
YES
CLASSIFICATION "NONSUB"
CLASSIFICATION "POSSIBLE SUB"
RETURN TO DETECTION ROUTINE WITH CLASSIFICATION

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13. ABSTRACT

One of the most difficult problems in ASW is the classification of submarines. Presently this is done by a subjective consideration of the contact's characteristics. This simulation attempts to reproduce this subjective process. The characteristics of doppler, aspect, edge alignment, trace length and bearing width are generated and then tested. If a sufficiently high degree of characteristic consistency and correlation is present the contact is classified as possible submarine.

The study is designed to duplicate fleet sonar contact classification percentages on selected contacts for use in a computerized ASW war game.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Sonar Contact Classification						
Simulation						

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